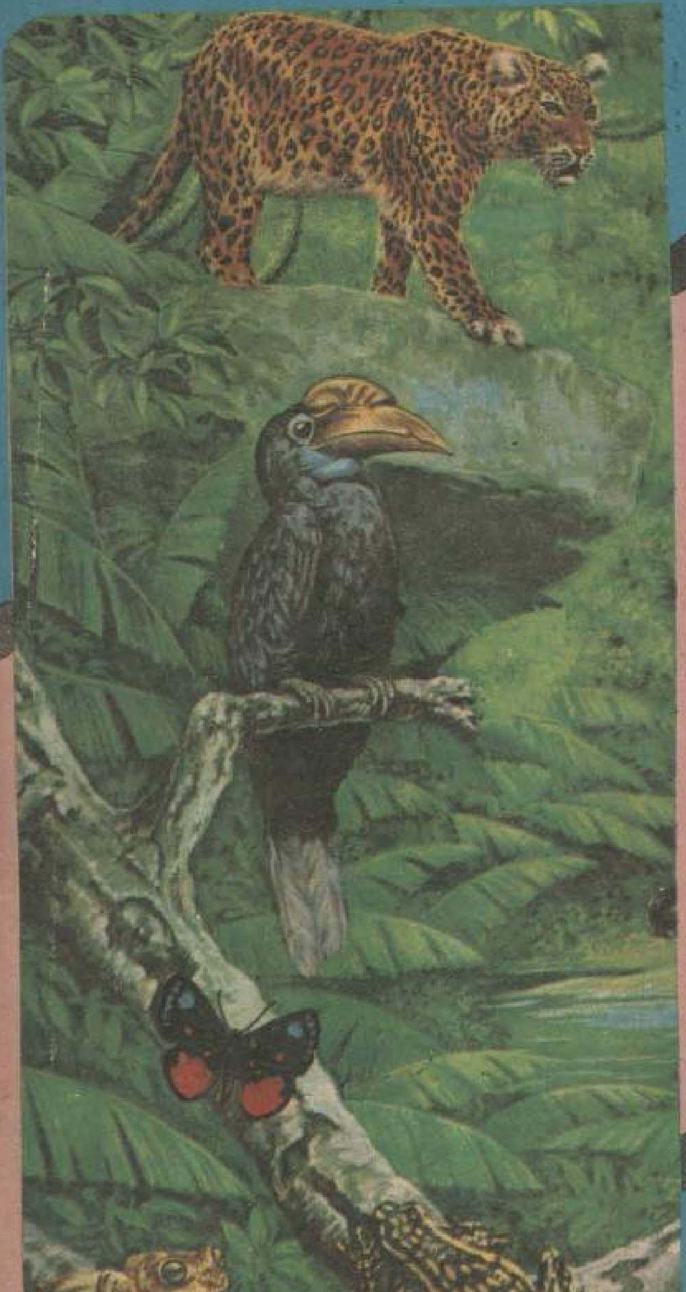
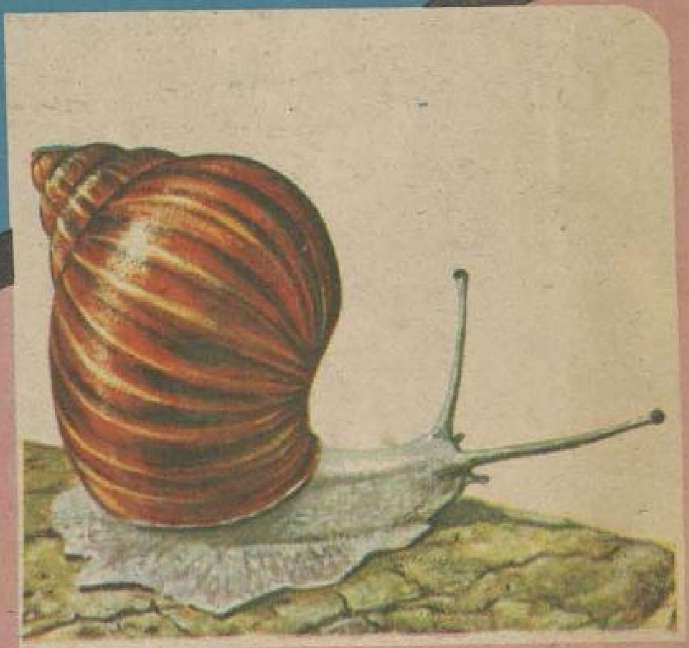
A TEXT BOOK
OF
BIOLOGY

Class XII





PUNJAB TEXT BOOK BOARD LAHORE

A TEXT BOOK
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Published by

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for

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PREFACE

"The essential of any good textbook is that it should be both accurate and general" wrote professor J.Z. Young (1950) in the preface of the first edition of his monumental book, *"The Life of Vertebrates"*. This dictum is perhaps more applicable when we are dealing with a textbook of biology at the intermediate level. Writing a textbook that should be both accurate and general is quite a difficult job. It is more so when several persons are involved in its writing. The various chapters of this book were written by the teachers who are well reputed in their respective fields. The original text was critically reviewed by the National Review Committee who suggested various changes in the manuscript. The authors of various chapters were then requested to incorporate the suggested changes. Thus the original text was revised and re- revised several times before it was sent to the press for publication.

After the release of the first edition a workshop was held, attended by the authors and teaching professionals, Necessary changes which were recommended by the members of the workshop has been incorporated in the present coloured edition. It is hoped that students and the teachers will find this new edition in a considerable improved and better form.

بسم الله الرحمن الرحيم

DIVERSITY IN FUNCTION: DIGESTION IN ANIMALS

1

One of the most important and fundamental differences between animals and plants is their mode of nutrition. The animals feed on complex organic materials such as proteins, carbohydrates, fats, etc., while the plants in general synthesize their food from inorganic materials such as water, carbon dioxide and minerals, etc., and build up the complex organic compounds. Since the green plants and certain bacteria are the only organisms which can synthesize the complex organic compounds from simple inorganic materials, animals depend entirely on them, either directly or indirectly, for the whole of their food materials and consequently for their continued existence. But inspite of the above differences, cellular metabolism is the basis for all the activities, both in plants and animals. In order for the metabolism to take place, food or nutrients must ultimately be presented to the organized components of the cell in a suitable state.

Broadly speaking, all animals have similar requirements. They have to obtain their nutrients directly from their external environment. Some of these nutrients such as oxygen, water and inorganic salts are usually readily available in the environment and their molecules and ions are all in a form that can enter the cells and be used. The rest of the nutrients, which we commonly call food, are usually in the form of proteins, carbohydrates, fats and vitamins, etc., and their molecules (except for some kinds of vitamins) are too large to pass into the cells through their membranes. Therefore, such complex compounds of large molecules must be broken down into simpler compounds of small molecules so that they can get into the cells. For example, proteins must be broken down into amino-acids, starches into simple sugars, fats into fatty acids and glycerols, because these then can readily pass through cell membranes. These changes involve mechanical, physiological and mostly bio-chemical processes and in these processes enzymes play a vital role. So the process by which the large complex food molecules break down into small, relatively simple molecules, essentially by the action of enzymes is known as **Digestion**. These small, simple organic molecules are used by the cells, in the performance of their different functions.

Digestion in Unicellular Animals

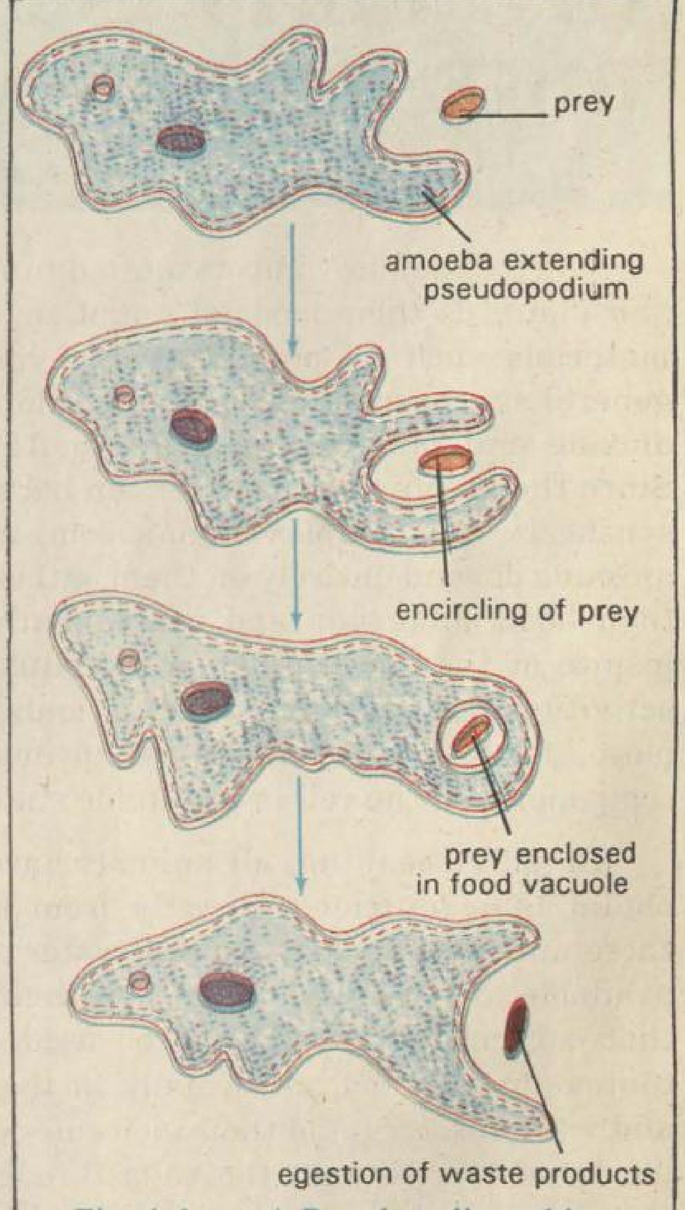
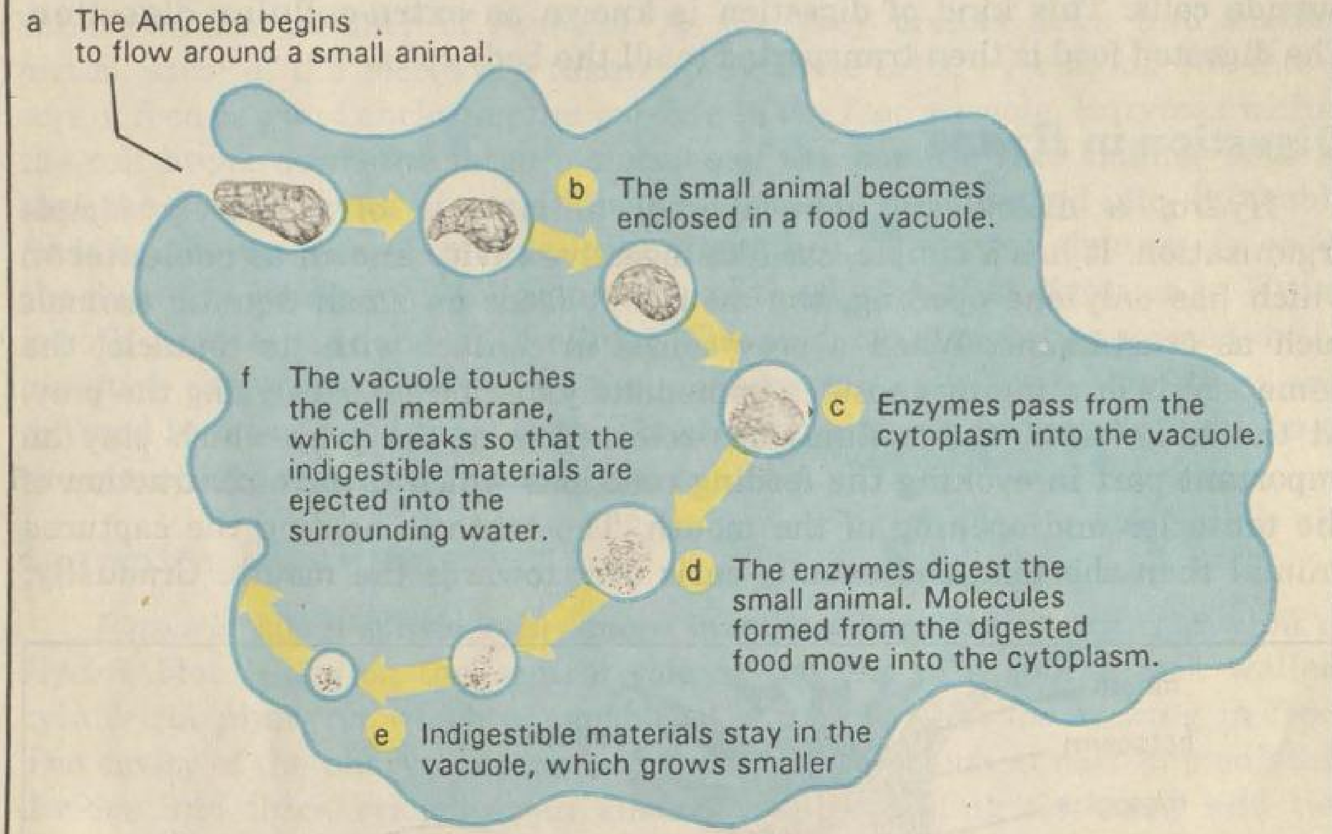

prey
amoeba extending pseudopodium
encircling of prey
prey enclosed in food vacuole
egestion of waste products

Fig 1.1. a A Pseudopodia making a food-cup.

Unicellular animals obtain their nutrients directly from their external aqueous environment. In some cases where nutrients are already in solution, these are usually readily taken up. But in most cases the nutrients are in the form of relatively larger and more complex particles that may be handled in different ways depending on the organism. Amoeba feeds on microscopic organisms such as algae, bacteria or other protozoans. When a food particle comes in contact with the outer membrane, it flows around it, forming a cup-shaped pseudopodial projection, a food-cup, which completely encloses or ingests the food, together with a droplet of water. (Fig 1.1). In this way a food vacuole is formed in the endoplasm. During activity, several food vacuoles may be formed. Digestion is mostly effected in the food vacuole by the enzymatic action. Enzymes are secreted into the food vacuoles by *Lysosomes* which are the vesicles in the cytoplasm containing hydrolytic enzymes responsible for intracellular digestion. It has been shown that the fluid in the vacuole is first acidic. Any live food is killed in the acidic medium. The acidic medium also softens up the food for further digestion. But as digestion proceeds, the medium of the food vacuole turns alkaline. This kind of digestion which takes place within a cell is known as **intracellular digestion**. The digested materials are absorbed into the surrounding cytoplasm and subsequently utilized in various metabolic reactions of the cell. In the whole process of digestion, diffusion and active transport play an important role for the transfer of molecules to and from the food vacuoles which themselves move around in the cytoplasm as shown in the diagram (Fig. 1.1.a.b).


a The Amoeba begins to flow around a small animal.
b The small animal becomes enclosed in a food vacuole.
c Enzymes pass from the cytoplasm into the vacuole.
d The enzymes digest the small animal. Molecules formed from the digested food move into the cytoplasm.
e Indigestible materials stay in the vacuole, which grows smaller
f The vacuole touches the cell membrane, which breaks so that the indigestible materials are ejected into the surrounding water.

1.1. b. Various stages of ingestion, digestion and egestion in Amoeba.

Digestion in Multicellular Animals

Most species of animals have bodies composed of many cells and most of the cells are far from the outside environment. The interior cells, therefore, are unable to obtain directly the substances they require from the environment as well as unable to dispose off their wastes directly into it. In the course of evolution, these problems have been overcome by the division of labour or specialization and devising special means of transport. In division of labour, different groups of specialized cells capture food, digest it, get rid of wastes etc., and thus constitute the digestive system. The transport system carries the digested food and other materials to each cell and removes waste substances from them. As the organism increases in complexity of structure and fuction, it becomes more and more organized and its cells become role. So the process by which the large complex food molecules break down into small, relatively simple molecules, essentially by the action of enzymes is known as **Digestion**. These small, simple organic molecules are used by the cells, in the performance of their different functions.

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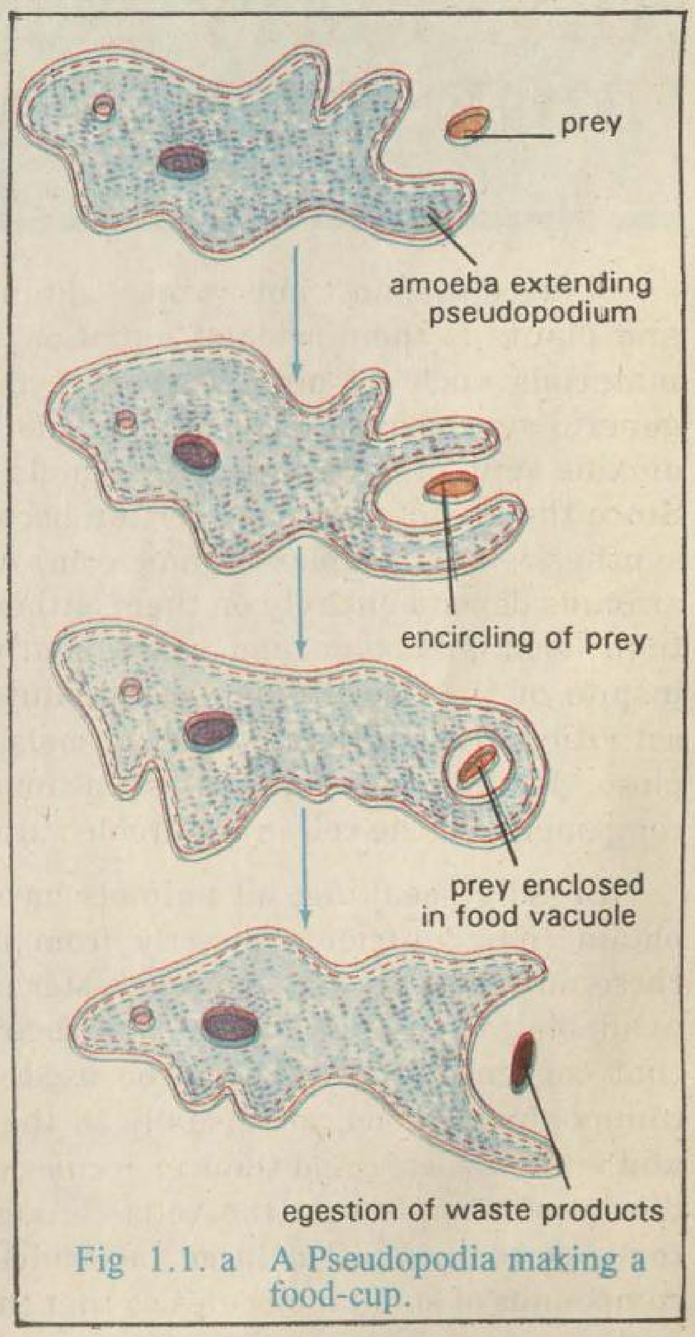
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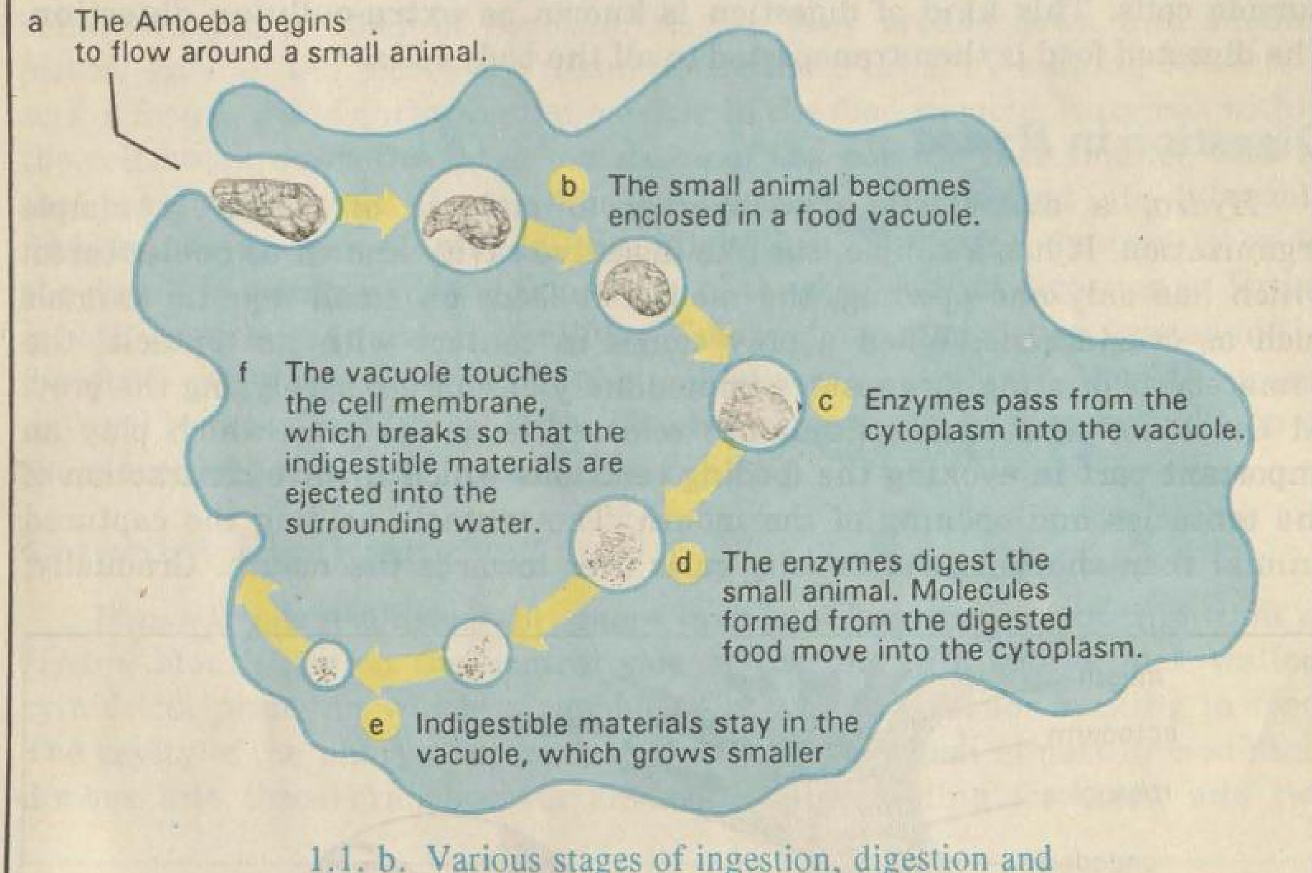
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Digestion in *Hydra*

Hydra, a diploblastic (two-layered) animal, is of relatively simple organization. It has a simple, sac-like digestive cavity known as **coelenteron** which has only one opening, the mouth. It feeds on small aquatic animals such as crustaceans. When a prey comes in contact with its tentacle, the nematocysts or stinging capsules immediately discharge, paralysing the prey. At the same time, tissue fluids are released from the prey which play an important part in evoking the feeding reactions which involve contraction of the tentacles and opening of the mouth. The tentacle holding the captured animal then shortens and usually curls over towards the mouth. Gradually,

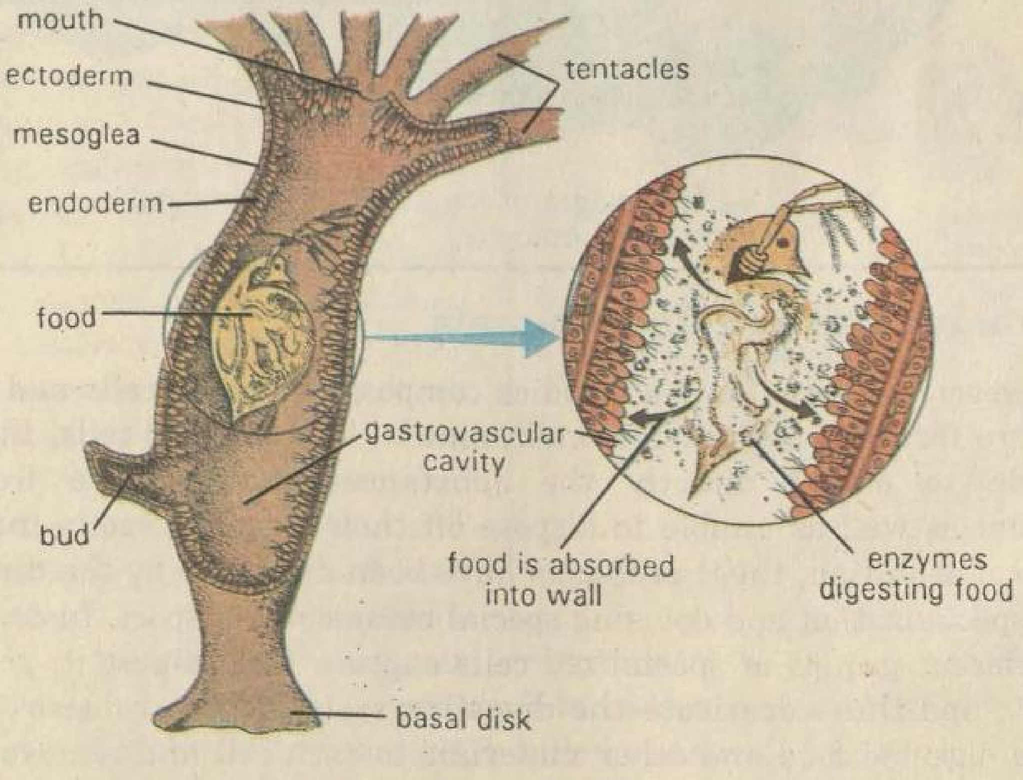


Fig. 1.2. Digestive System of Hydra

the other tentacles bend over the one holding the prey and finally all the tentacles shorten so the food is brought over the mouth which opens widely and engulfs the prey. The food is then pushed into the digestive cavity. The endodermal cells lining this cavity secrete enzymes into this cavity that begin the process of digestion which is therefore **extracellular**. But much of the digestion takes place within the cells lining the cavity. These digestive cells behave in the manner of Amoeba. As the prey breaks down into smaller pieces, some of the pieces are taken up by these cells, by bulging out into a sort of food cup and enclosing the particle in the food vacuole. Enzymes within the cell break down the large molecules of the particle into smaller ones so that the various types of non-diffusable nutrients are changed into diffusable form by the process of **intracellular digestion**. The same changes go on in the digestive cavity with the remainder of the food so that digestion in Hydra is both extracellular and intracellular. The products of digestion formed in the digestive cavity are absorbed by the endodermal cells and then they are diffused into the ectodermal cells. The undigested particles are brought up to the mouth and removed through it (Fig. 1.2).

Digestion in a Planarian

Planaria has a considerably more intricate digestive cavity than that of *Hydra*. Mouth lies on the ventral side at the end of a short, thick walled, cylindrical **pharynx** which is capable of protruding out for sucking in food. The cavity of the pharynx opens into the intestine which almost immediately divides into three branches, an anterior one extending forwards, and two

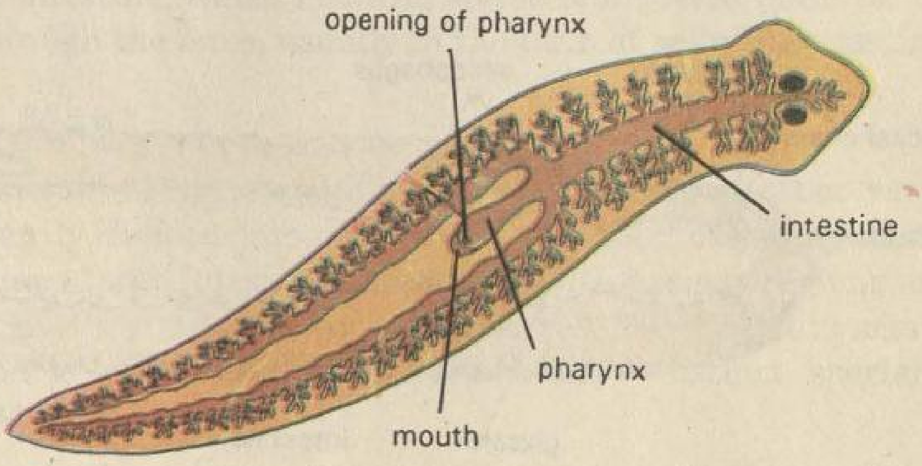


Fig 1.3. Alimentary canal of Planaria.

lateral branches extending backwards. Each of these three main branches gives off numerous small branches which end blindly and may be called intestinal caeca. So the whole system forms a branching gastro-vascular system extending throughout the greater part of the body so as to increase the surface concerned with digestion, absorption and distribution of food (Fig. 1.3).

The food of a planarian consists mostly of dead aquatic animals but it can capture live aquatic organisms as well. Digestion is essentially like that of *Hydra,* being extracellular as well as intracellular. Moreover, there is only one opening, the mouth and no separate transport system. The ramifying branches of the intestine serve to transport the digested food to other tissues. Undigested particles pass out of the mouth.

Digestion in Earthworm

All other major groups of animals from annelids upwards possess a tubular rather than sac-like digestive tract extending from mouth to anal opening. Such an arrangement permits a one-way passage of food materials and allows for the structural and functional modifications of the digestive tube along its length. In the first part there are organs which are concerned with the physical and chemical conversion of food into smaller sized particles. The middle part is concerned with the final digestion and then absorption of the digested materials from the gut into the circulatory system; and the end part is concerned with the elimination of the undigested food residue.

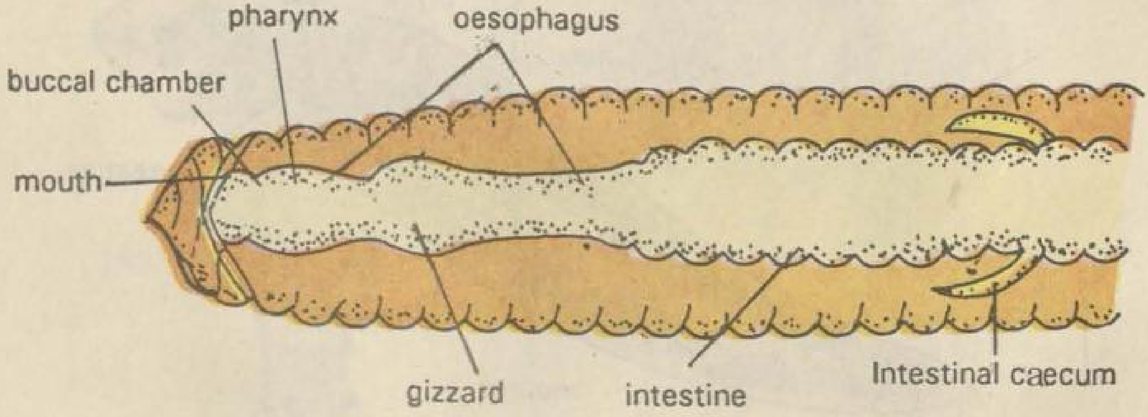


Fig 1.4. Alimentary canal of earthworm

The digestive system of earthworm is, therefore, highly specialized. Mouth lies at the anterior end, overhung by a small lobe, and opens into a short, wide, thin-walled **buccal cavity**. This leads into the **pharynx** which has thick, muscular walls and can protrude slightly out of the mouth to suck soil containing decaying organic matter, which is the food of the earthworm. The lining of the pharynx has pharyngeal glands. These glands secrete mucous and a proteolytic enzyme into the pharyngeal cavity. The **oesophagus**, which follows the pharynx, is a thin-walled narrow tube having internal glands especially in the region behind the gizzard. These glands secrete crystals of calcium carbonate that enter the gut. The calcium carbonate may help to neutralise organic acids in the food thus making it easy for the alkaline digestive juices of intestine to act upon it. The oesophagus enlarges forming a thick-walled, muscular region, the **gizzard**, whose epithelial lining bears a distinct cuticle. Here the food material is ground and broken into extremely small particles. Some part behind the gizzard is again narrow and may be called **oesophagus** but due to its important glands, this part is sometimes called **stomach** (Fig. 1.4).

The oesophagus in turn opens into the longest part of the gut, the **intestine**. The cells that form the lining of the intestine secrete enzymes that complete the process of digestion. The first part of the intestine has its dorsal wall folded into a U-shaped structure known as **typhlosole** which increases the area for absorption. Moreover, there is a pair of very small **intestinal caeca** in the anterior region that also pour digestive juices. The digested food is absorbed by the intestinal epithelium and directly passed by means of diffusion and active transport into the blood capillaries of the intestine. The last part of the intestine, called **rectum**, stores undigested material before it is passed out through the anus, usually in the form of pellet-like castings.

Digestion in Man

The organization of the alimentary canal in man and other vertebrates can be conveniently divided into oral cavity, pharynx, oesophagus, stomach, small intestine and large intestine. Associated with various regions are many glands, such as salivary glands, liver and pancreas. Due to great variability in diet, various parts of the digestive system show distinct specializations (Fig. 1.5.a).

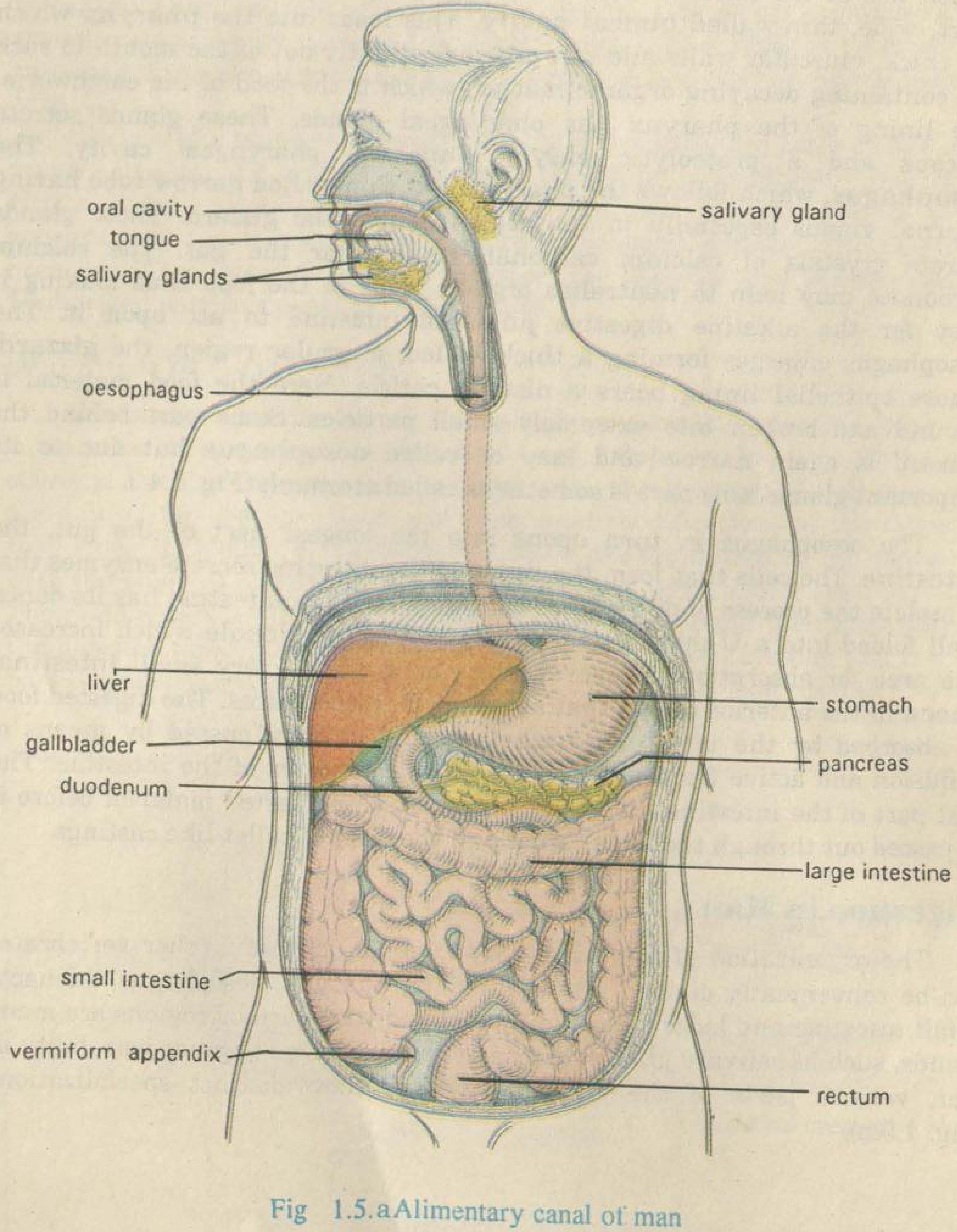

oral cavity
tongue
salivary glands
salivary gland
oesophagus
liver
stomach
gallbladder
pancreas
duodenum
large intestine
small intestine
vermiform appendix
rectum

Fig 1.5.a Alimentary canal of man

Digestion in The Oral Cavity

The oral cavity is the site of entrance of food into the digestive tract and consists of several important structures such as palate, tongue, teeth and openings of salivary glands, etc., all performing specific functions. Sight, smell and taste play a very important role in the selection of food in human diet. Social and psychological factors are also involved in preferring a certain type of food over the other. Food taken into the mouth cavity is at once subjected to the grinding action in which teeth, cheeks, and tongue all take part so that the morsel of food is physically and quickly broken down into smaller pieces. At the same time, the process of lubrication and digestion of food starts right from the oral cavity. The three pairs of the salivary glands secrete saliva which contains three important ingredients: (a) Water and mucous which together make a slimy liquid that serves principally to moisten and lubricate the ingested food so that it can be chewed efficiently and to allow the digestive juices to enter the food mass; (b) sodium bicarbonate and some other salts which are slightly antiseptic but their main function is to stabilise the pH of the food. Fresh saliva is alkaline with a pH nearly 8 but quickly loses carbon dioxide and gets to pH 6; (c) A carbohydrate enzyme amylase or ptyalin which hydrolyses starch and glycogen to maltose. So as a result of mastication, the softened, partially digested slimy food mass is now arranged into small oval lumps, each called bolus, and these are pushed to pharynx by the combined efforts of the cheek muscles, the floor of the buccal cavity and the tongue. The pharynx plays an important role in swallowing during which the muscular walls of the pharynx contract, squeezing the bolus and forcing it downwards into the oesophagus. The larynx or first part of trachea is elevated causing a lid like epiglottis to close over the glottis or entrance to the trachea over which the bolus must pass enroute to the dorsally placed oesophagus. At the same time the base of the tongue and the muscular walls surrounding the entrance to the pharynx block the movement of the bolus back to the mouth cavity.

The Oesophagus

The foodpipe or oesophagus is a muscular tube extending from the pharynx, through the diaphragm into the stomach. As the food passes slowly down the oesophagus, the salivary amylase keeps acting on the food and continues to digest the starch and glycogen until the acidic juice of the stomach is able to penetrate the food mass so as to bring about a change in pH and thus putting amylase out of action.

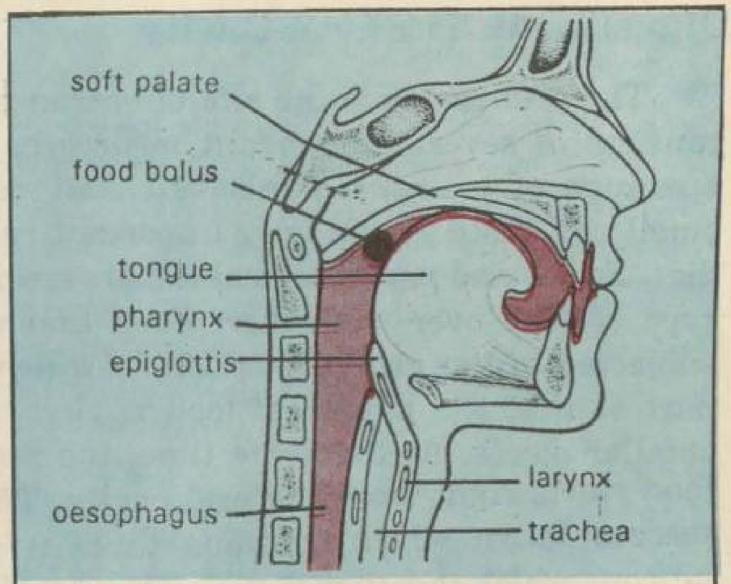


Fig. 1.5b.
Digestive passage across in the pharynx.

The food is carried through the oesophagus, and later on through the stomach and intestine, by a series of rhythmical involuntary wave-like contractions of the muscular walls, known as **peristalsis**. In this process, the part of the tube containing the bolus starts contracting just behind the mass, thereby squeezing the food into the next part of the tube where the muscles have relaxed thus making room for it. The hinder part from where the mass has pushed down relaxes again. Normally, the direction of the wave of contraction of the muscles is from the oesophagus to the stomach and then from the stomach to the intestine, but if there is some irritation of the oesophagus or stomach, then the process of peristalsis may be reversed and vomiting occurs. This reversal is called **anti-peristalsis** (Fig. 1.5.b).

Digestion in The Stomach

The site at which the oesophagus joins and empties into the stomach is called the **cardiac sphincter** where the ring-like muscles keep in a contracted state thus closing the stomach from the oesophagus and preventing regurgitation. But on the peristaltic reflex the cardiac sphincter relaxes to allow the food into the stomach. The walls of the stomach are complex, with three layers of muscles which are responsible for the grinding or churning action of the stomach (Fig. 1.6).

The inner lining of the stomach consists of tubular gastric glands which secrete gastric juice which is poured into the stomach cavity by means of small ducts. The gastric juice is a mixture of several substances, mainly **water, mucous, pepsin** and **hydrochloric acid**.

Mucous forms a coating over the stomach lining and functions as an important protective layer. It neutralises the acid and inhibits the enzymatic action of pepsin on the wall of the stomach.

Pepsin is an enzyme secreted in an inactive form called **pepsinogen** by special glandular cells. Pepsinogen is activated to pepsin when exposed to the

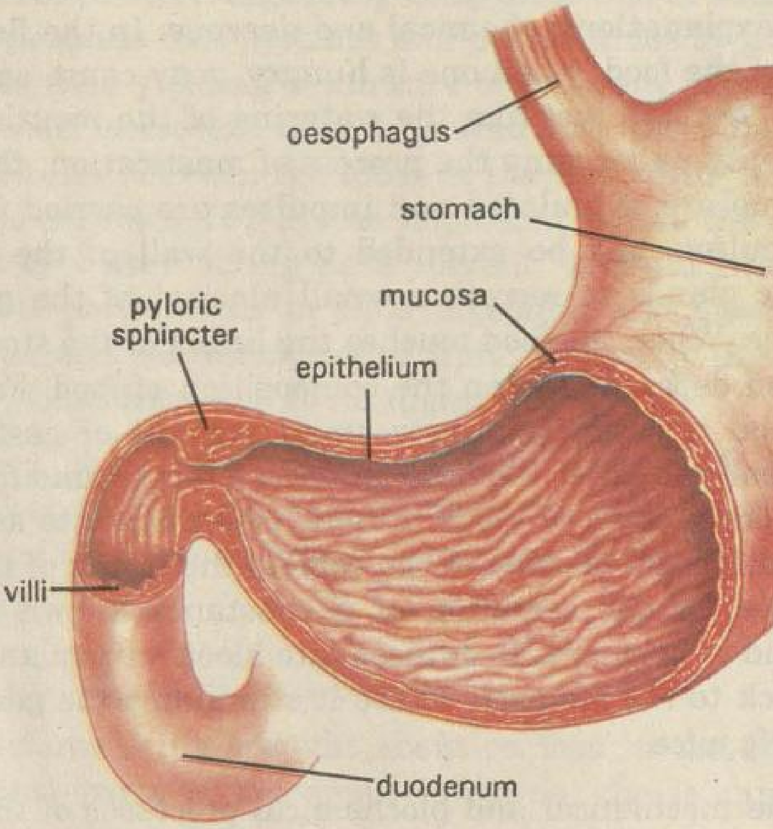


Fig 1.6. Middle part of the gut showing the stomach and duodenum

acidic medium of the stomach or to some already activated pepsin. Pepsin hydrolyses proteins to yield smaller fragments of polypeptides and peptides. Hardly any amino-acids are produced by its action.

Another enzyme called **Renin** is present in the gastric juice of several mammals in the infant stage but is hardly distinguishable from pepsin in the human infants. It helps to precipitate milk proteins.

Hydrochloric acid is probably the most unusual component of the gastric juice. It is secreted by specialized glandular cells in a remarkably concentrated form having a pH of about 1.3. The final pH of gastric juice is in the range of 2 to 3 as a result of dilution. The most important function of the hydrochloric acid is to provide suitable acidic conditions for the activation of pepsinogen to pepsin and enabling the latter for its optimal enzymatic activity. The very low pH of the acid is also responsible for the precipitation of many soluble proteins. The strong acid also functions to kill many micro-organisms.

The question arises: what causes gastric juice to be secreted? There seem to be two important explanations: chemical and nervous. In the first instance, the smell and sight of the food, when one is hungry, may cause small amount of gastric juice to be secreted just like the watering of the mouth. When the food is in the oral cavity undergoing the process of mastication, the nerves in the cheeks and tongue are stimulated and impulses are carried to the brain from where the impulses may be extended to the wall of the stomach to stimulate the gastric glands to secrete a small amount of the gastric juice before the food arrives. When the food touches the lining of the stomach, more gastric juice is poured depending upon the composition of food. For example, when only starch food is eaten relatively small amount of gastric juice is secreted while for meat and other kinds of proteins a larger amount of gastric juice is poured. Breaking down of large protein molecules into smaller ones provides a chemical stimulus to some of the cells of the lining of the stomach which are responsible for the secretion of a substance known as **gastrin** which is in fact a kind of hormone. It diffuses into blood stream and is carried by the capillaries back to the stomach where it stimulates the gastric glands to secrete more gastric juice.

As a result of the mechanical and biochemical processes of the stomach, food is changed into a nearly homogeneous semifluid called **chyme**. How long the food stays in the stomach depends on the consistency and quality of the food. For example, fluids pass on in 20 minutes to half-an-hour. Solid foods of simple nature take 2-3 hours to be converted to chyme while spicy, fatty and rich food may take 3-4 hours.

Digestion in Duodenum

The first 12 inches or so of the small intestine leading from the stomach is called the **duodenum** but it is a very important region for digestion. The pyloric sphincter at the distal end of the stomach opens to allow a small amount of chyme at a time to pass into the duodenum. The secretions of two important glands, the **liver** and the **pancreas** pour into the duodenum when food enters here. Pancreatic juice comes down from the pancreas by means of a pancreatic duct. Pancreatic juice is slightly alkaline with a pH of about 8 and thus partially neutralizes the acidic contents emerging from the stomach, at the same time providing a more suitable medium for the action of its digestive enzymes. The pancreatic juice contains several important enzymes: (1) **Amylase** or **Amylopsin** which is the starch-digesting enzyme and is similar to salivary amylase in action. But, it is more effective in hydrolysing the polysaccharides to maltose and even glucose. (2) **Lipase** is the principal enzyme responsible for the hydrolysis of fats. (3) The pancreatic juice also contains several **protein-digesting enzymes.** One of such enzymes is **trypsin** which splits proteins into peptides and polypeptides by attacking the internal peptide bonds thus yielding a mixture of different peptides and amino-acids. Bile is the other secretion that is poured into the duodenum from the gall bladder which lies between the lobes of the liver. Bile is a greenish fluid and it contains no enzymes. It plays an important role in the digestion of fats. Bile is composed of **water** acting as a solvent, **sodium bicarbonate** and some other salts. It participates in lipid digestion and absorption by promoting emulcification and solubilization of lipid, including the fat-soluble vitamins and the fatty acids liberated in fat digestion.

Moreover, there are certain glands embedded in the wall of the duodenum that produce mucous, water and sodium bicarbonate to help in the lubrications of food, protection of intestinal lining and maintaining a pH of about 7.8.

Digestion in Jejunum and Ileum

The reactions being brought about on food in the duodenum are carried on in the next parts of the small intestine, the jejunum and ileum. As a matter of fact there is no demarcation between these parts of the small intestine and its division into these parts is arbitrary. The lining of the jejunum and ileum secretes several enzymes in the intestinal juice that complete the process of digestion of proteins, carbohydrates and fats. The **amino-peptidase** enzyme splits polypeptides to dipeptides and amino-acids; **enterokinase** releases trypsin from its bondage and allows the hydrolysis of polypeptides to proceed. **Dipeptases** such as **erepsin**, splits the remaining peptide bonds so that all the proteins split into amino-acids. Maltase, lactase, etc. bring about hydrolysis of sugars into simple sugars especially glucose and lipase completes the digestion of fats into fatty acids and glycerols.

Absorption in The Small Intestine

The inner epithelial lining of the small intestine provides an enormous surface for the absorption of nutrients. This is because of its innumerable microscopic finger-like projections called **villi** distributed over the entire inner surface of the small intestine, giving it a soft, velvety appearance. Each villus consists of blood capillaries, lacteals and an outer covering of a single layer of epithelial cells (Fig. 1.7). These cells exhibit properties of selective absorption and active transport. Simple sugars and amino-acids pass through the epithelial lining of the villi and then enter the blood stream directly by way of the blood capillaries of the villi. The products of fat digestion such as fatty acids and glycerols enter the lymph vessels or lacteals of the villi, while the shorter-chain fatty acids and possibly glycerine which is water soluble are absorbed by the blood capillaries rather than lacteals.

As stated above most of the absorption takes place in the small intestine but some water, alcohol and mineral salts get diffused into blood in the stomach. Certain drugs and hormones can even be absorbed in the mouth.

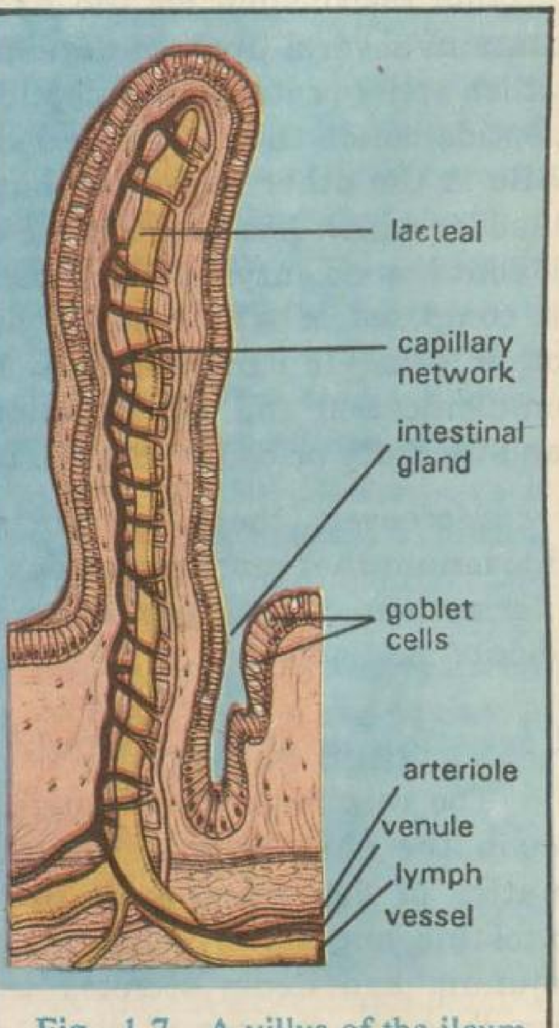


Fig 1.7. A villus of the ileum

The Large Intestine

The large intestine can be differentiated into a long **colon** having an ascending, a transverse and a descending portion, a small **caecum** and the terminal part or **rectum**. The portion of the colon below the T-shaped junction with the small intestine is the caecum. It bears a small, blind, finger-like projection called **appendix**. Sometimes the waste materials may be trapped in its cavity and an infection results which is called **appendicitis**. It causes extreme pain and the appendix may have to be removed.

The large intestine performs several important functions. One important function is the absorption of water and salts from the residual chyme which comes from the small intestine. The water which is absorbed is not only the one taken with the food but also from the secretion of the salivary glands, and digestive tract that mixed with the food. If this reabsorption of water and salts does not take place due to some reasons such as physical irritation, infection, drug action or emotional disturbance, a condition known as **diarrhoea** is caused. If this condition is permitted to go unchecked, it will lead to dehydration and excessive loss of salts that may prove to be fatal, especially in infants. At the other extreme an unusually slow passage of residual chyme through the large intestine may be responsible for excessive absorption of water and thus results in constipation. It is usually accompanied by lack of mucscular activity, which in turn, may be due to emotional disturbances. Another important function of the large intestine is performed by the bacterial population that it contains.

These bacteria may be able to synthesize certain vitamins and other materials and thus help in meeting some of our nutritional requirements. In herbivores, caecum is large and a storehouse of special bacteria, which break down cellulose walls of cells of vegetable food thus using the cellulose that we are not able to use.

The last part of the large intestine is the rectum at the end of which is the anus that is guarded by sphincter muscles. Under ordinary circumstances, as the rectum is filled and compacted with faeces it gives rise to the defecation reflex. This reflex can be consciously inhibited in individuals other than infants. The faeces which is eliminated consists of undigested food residue, remains of the bile pigments, minerals, dead epithelial cells of the intestinal mucosa and bacteria.

QUESTIONS

1. What is the fundamental difference between animals and plants in their mode of nutrition?
2. How would you define the term digestion?
3. Illustrate various stages of ingestion, digestion and egestion in Amoeba.
4. What is the difference between extracellular and intracellular digestion?
5. Describe the process of digestion in Planaria.
6. What type of chemical and mechanical changes occur in food in the oral cavity of man?
7. Describe main steps of digestion of food in the stomach of man.
8. What type of products of digested food are absorbed by the lacteals and blood capillaries of villi?
9. What is the function of large intestine?

TRANSPORTATION IN ANIMALS

2

Most unicellular animals obtain food and oxygen for their metabolic needs directly and continuously from their aqueous environment. The resulting waste products of metabolism, including carbon dioxide, are in turn given out of the cell directly to the external surroundings. The molecules and ions of substances dissolved in body fluids or a cell's cytoplasm are never at rest. Similarly, the external environment in the immediate vicinity of cells is continuously being renewed chiefly by currents arising from temperature differences and the movement of the organism. The movement of molecules and the concentration gradient in and out of the cells results in diffusion through the cell membrane because the cell membranes are differentially permeable. Therefore, in the one-celled organisms, and even in the simple multicellular animals such as sponges and coelenterates, diffusion of various substances is the sole process to meet the requirements of cells (Fig. 2.1).

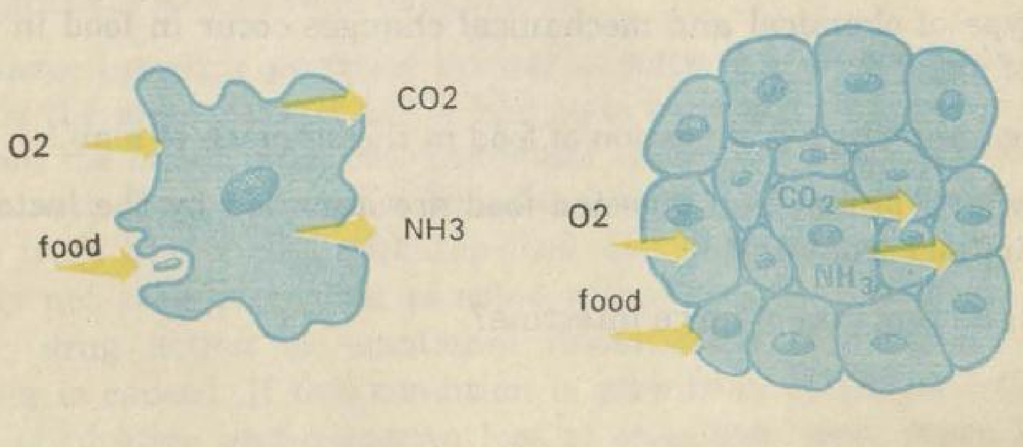


Fig 2.1. The multicellular problem in transport in contrast with the unicellular

In higher animals, which are large in size and complex in organization, diffusion alone cannot serve the purpose because it is a very slow process and can be useful only from cell to cell or, cell to environment and vice versa. Some more effective and efficient means of transporting materials, from one part of the body to another, would be required if the animal is to survive.

Transportation in *Hydra*

Hydra can be seen with the naked eye, being 2-3mm in length and about half a millimeter in diameter. It has no specialized transport system. The whole of the outer surface of the body is in direct contact with the outer environment (water) and the internal lining is in contact with the internal environment, mainly water, and digestive fluids. Therefore, the process of diffusion is sufficient to meet the needs of getting nutrients in and getting rid of the wastes. After the food has been digested in the digestive cavity, the molecules of glucose, amino-acids, etc., are made available to the cells lining the cavity by diffusion. Additional sugars, amino-acids and fatty-acids, are made available to the cells directly by the digestion within the cells. Since the cells of the outer layer have similar requirements, they have to depend on the inner cells for their organic food substances and they receive these substances again by diffusion and active transport. Some of the cells of the inner lining have **flagella** which keep the internal environment in motion. Thus keeping the food molecules reach every cell of the lining.

The large surface presented to the water by both the ectoderm and endoderm of the body facilitates gaseous exchange and nitrogenous excretion, but the same conditions favour the influx of water into the tissues. *Hydra,* therefore, has to osmoregulate and maintain a balance of ions in body fluids in comparison with the surrounding water.

Transportation in a Planarian

Although a planarian is large as compared with protozoans and coelenterates, yet it does not possess any special transport system. There are several reasons for this. Firstly, the body is greatly flattened so that most cells are close to the outer surface. Secondly, the loose arrangement and thin layering of the cells are such that diffusion is adequate for the exchange of nutrients and waste products.

As has been stated earlier, digested food materials are distributed directly by the sac-like **intestinal caeca**, to most of the internal parts of the body so there is no need for a separate transport system for the distribution of food. However, for the transport of liquid wastes and their removal to the outside there is a special excretory system.

Transportation in Earthworm

In segmented worms, and in all vertebrates including man, there is a special transport system or the circulatory system consisting of predominently closed tubes in which the blood flows and keeps in circulation due to pumping action of the heart. The blood flows from arteries to veins by way of capillaries. The capillaries are microscopic blood vessels lined with a single layer of cells. It is during the passage of blood within the capillaries that the interchange of nutrients and waste products between the blood and the tissue fluids occurs, resulting in definite changes in the composition of the blood. This kind of system which does not permit blood to come in direct contact with the cells is known as **closed circulatory system**. It is regarded as the most advanced type, having greater efficiency, maintenance of blood pressure, and economy of blood volume. In earthworn, the arrangement of blood vessels and their relationship with the pumping vessels is very complicated, so a generalized plan of this system is given here. There are three main blood vessels running in longitudinal direction, four or five pairs of contractile vessels or **'hearts'** and smaller vessels. The first main blood vessel is the **dorsal blood vessel** which runs along the mid-dorsal line from the anterior end of the body to the posterior end, lying above the alimentary canal. In the intestinal region of the body, from the 14th segment backwards, the dorsal vessel serves as a collecting or receiving vessel and has thick, muscular walls which contracts rhythmically, driving blood from behind forwards. It receives blood from nephridia and other organs. In the first thirteen segments the dorsal vessel becomes the distributing channel. It sends whole of its collected blood into five pairs of 'hearts' which pump the blood into the ventral vessel (Fig. 2.2.).

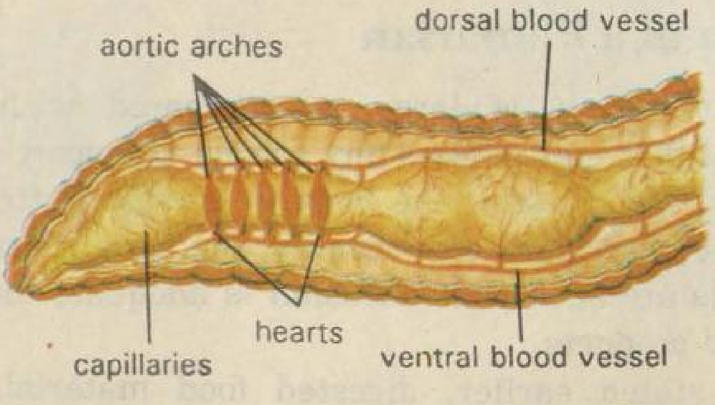


Fig 2.2. Blood circulatory system in the anterior part of earthworm

The second main blood vessel is called the **ventral vessel**. It runs below the intestine and the direction of flow of blood is backwards. It is the chief distributing channel in the body including the anterior region. It gives off a number of small blood vessels which distribute blood to the body wall, septa and nephridia of each segment.

The third main blood vessel is called the **sub-neural vessel**. It is small vessel, running ventral to the ventral nerve cord and extends from the posterior end to the anterior region, the direction of flow of blood is backwards. It collects blood from the ventral region of the body wall and communicates with the dorsal vessel through connecting vessels in each segment. The sub-neural vessel on entering the first thirteen segments divides into two main branches, each running along the side of the oesophagus and collects blood from the body wall, septa, nephridia and reproductive organs.

Hearts: There are four or five pairs of hearts depending on the species, lying in the 7th to 13th segments. They are also called **pseudo-hearts**. These pump the blood from the dorsal to the ventral vessel.

In all instances the vessels which supply blood to the various parts of the body are connected to the vessels which drain these parts by a network of capillaries. The direction of the circulation is aided by a system of **valves** which are present in the dorsal vessel, in the hearts and at the points of junction of the chief vessels with the dorsal vessel. The blood plasma is red with dissolved haemoglobin and contains colourless nucleated corpuscles. The branches of the ventral vessels that enter the walls of the digestive tract break up into capillaries. Diffusion occurs quite rapidly through these walls and the end products of digestion such as amino-acids and glucose pass through the lining of the intestine to enter the capillaries. Once in the blood stream, these products are distributed to all parts of the body.

Transportation in Grasshopper

The main system for the transport of food and waste materials is the blood vascular system while there is a separate transport system for gases. In insects and other arthropods, the circulatory system is known as **open circulatory system** because there are no vessels or capillaries and for much of the time, the blood flows in large spaces. The main body cavity is not true coelom but it is known as **haemocoel** in which the blood flows freely and bathes all the viscera lying in it. The blood or **haemolymph** is a colourless fluid, in which float numerous large white corpuscles (Fig. 2.3).

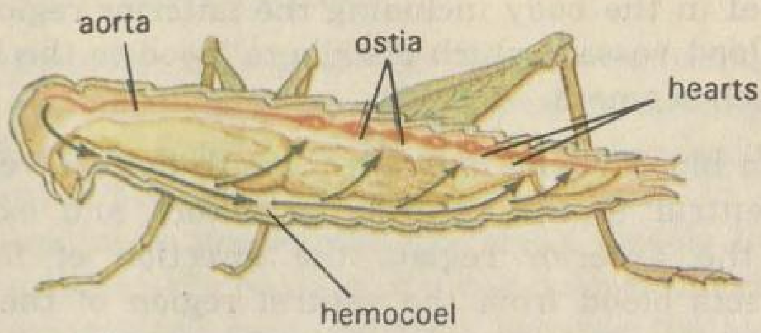


Fig 2.3. The heart of grasshopper and movement of fluid

The circulation of the blood is brought about by tubular dorsal vessel extending in the mid-dorsal line immediately below the terga. The portion of the dorsal vessel, limited to the abdomen is called **heart** and the part which extends in the thoracic and head region is called the **aorta**. The heart lies in a cavity known as **pericardial sinus**. In the floor of the pericardium, which forms a kind of **diaphragm**, there are small apertures by which the pericardial sinus communicates with the main haemocoel.

The heart is divided into eight chambers each of which is provided with a pair of lateral openings, the **ostia**, which are protected by valves to prevent the outflow of blood. The aorta is without chambers and it opens anteriorly by a funnel-shaped opening into the haemocoel. On the sides of the heart there are special muscles which help in the flow of blood. The blood flows from the heart to the aorta from where it is poured into the main cavity of haemocoel in the head region. It moves back through the cavities of the body bathing the body tissues as it goes along. Then the blood returns from the haemocoel into the pericardial sinus and then enters the heart through the ostia.

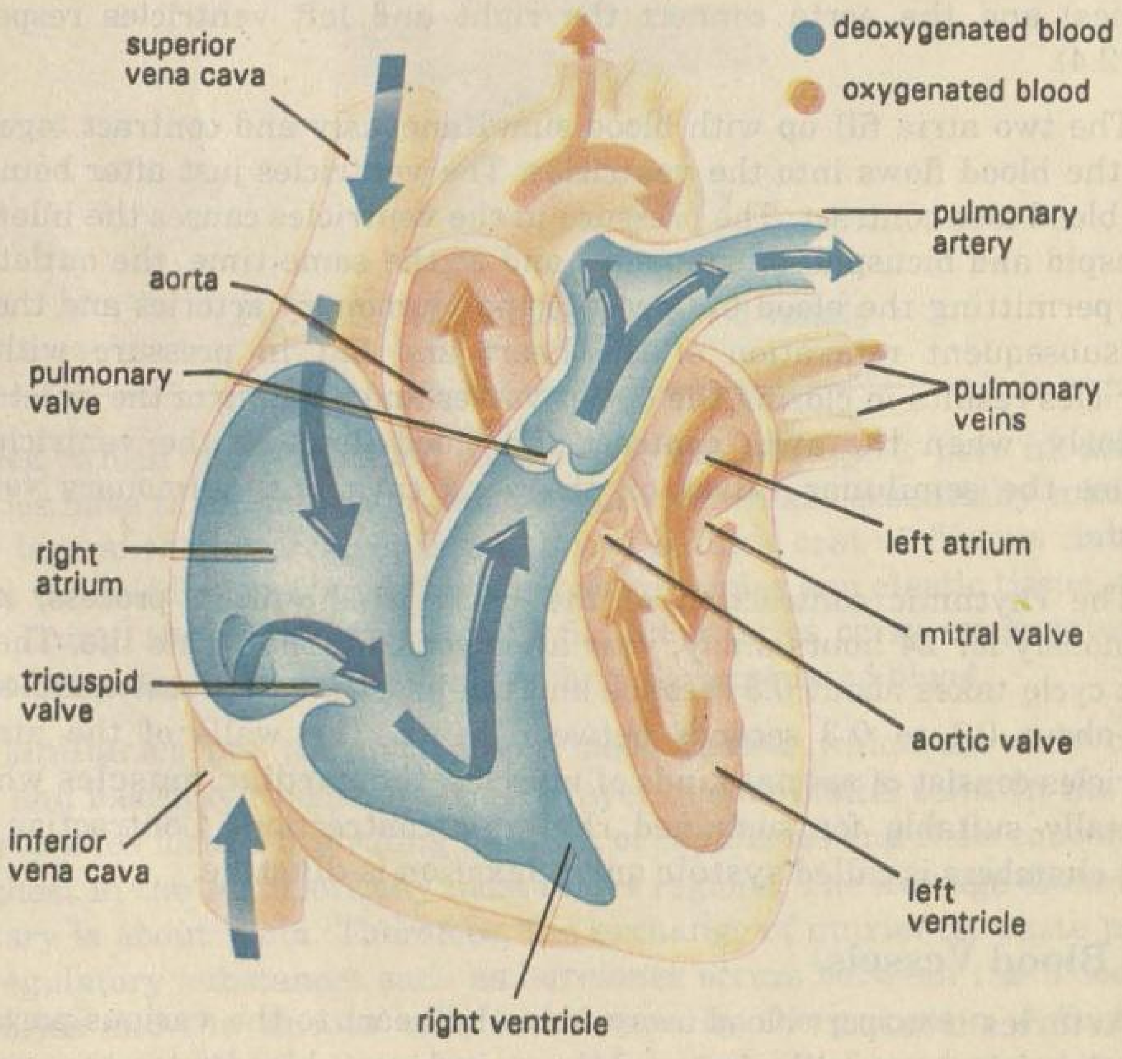
So we find that an open blood system is built on quite a different plan from the closed system of that of the earthworm owing to the different habitats and requirements.

Transportation in Man

In man, there is a closed circulatory system but an additional network of vessels also exists, co-ordinated with it, which is known as **lymphatic system**. Thus there are two circulatory fluids, blood and lymph for the transport of nutrients, waste materials and respiratory gases.

The Heart

The heart is a muscular pumping organ enclosed by a tough membrane, the **pericardium**. There is a fluid between the heart and the pericardium which reduces friction during heart beat. The inextensible pericardium is also thought to prevent the heart becoming over-extended with blood in certain extreme conditions. The heart consists of four chambers, the upper two are the **atria or auricles** and the lower two the **ventricles**. The right and left sides are completely separate, containing deoxygenated and oxygenated blood, respectively. The atria receive blood and the ventricles distribute it. The blood flows into the right atrium by means of a **superior vena cava**, which brings the deoxygenated blood from the upper region of the body such as the head



deoxygenated blood
oxygenated blood
superior vena cava
pulmonary artery
aorta
pulmonary valve
pulmonary veins
left atrium
right atrium
mitral valve
tricuspid valve
aortic valve
inferior vena cava
left ventricle
right ventricle

Fig 2.4. The path of blood through the human heart.

and the arms, and an **inferior vena cava** that brings the deoxygenated blood from the lower region of the body. The right atrium opens into the right ventricle through an opening which is guarded by the **tricuspid valve**. It is made up of three flaps of connective tissue whose free edges are attached by elastic strings to the ventricular wall. From the right ventricle, the blood is propelled by way of the pulmonary arteries to the lungs, for oxygenation. The aerated blood returns from the lungs by means of pulmonary veins into the left atrium. This blood flows into the left ventricle by an opening guarded by **bicuspid valve** consisting of two flaps instead of three. By the contraction of the left ventricle, the blood is pumped into the aorta which carries the blood to all parts of the body. Each ventricle is also equipped with an outlet valve known as **semilunar valve**, of different construction, opening away from the heart at the sites where the plumonary trunk (leading to the two pulmonary arteries) and the aorta connect the right and left ventricles respectively (Fig. 2.4).

The two atria fill up with blood simultaneously and contract together so that the blood flows into the ventricles. The ventricles just after being filled with blood also contract. The pressure in the ventricles causes the inlet valves (tricuspid and bicuspid) to snap shut and at the same time the outlet valves open permitting the blood to flow into the plumonary arteries and the aorta. The subsequent relaxation of the heart and fall in pressure within the ventricles results in closing the outlet valves and opening of the inlet valves. Similarly, when the atria contract the blood flows to the ventricles only because the semilunar valves on the vena cava and pulmonary veins are closed.

The rhythmic contraction of the heart is a built-in process; it beats continously for 24 hours a day, year after year, for the whole life. The whole heart cycle takes about 0.8 seconds and the heart muscles rest completely for only about 0.1 to 0.3 seconds between beats. The walls of the atria and ventricles consist of special kinds of muscles, the **cardiac muscles** which are especially suitable for sustained rhythmic contraction. Contraction of the heart chambers is called **systole** and relaxation is **diastole**.

The Blood Vessels

Arteries transport blood away from the heart to the various parts of the body through the **capillaries**, and the **veins** carry blood from the capillaries back to the heart. Arteries vary considerably in size, from the largest artery or aorta which is about an inch in diameter, while the small branches of the

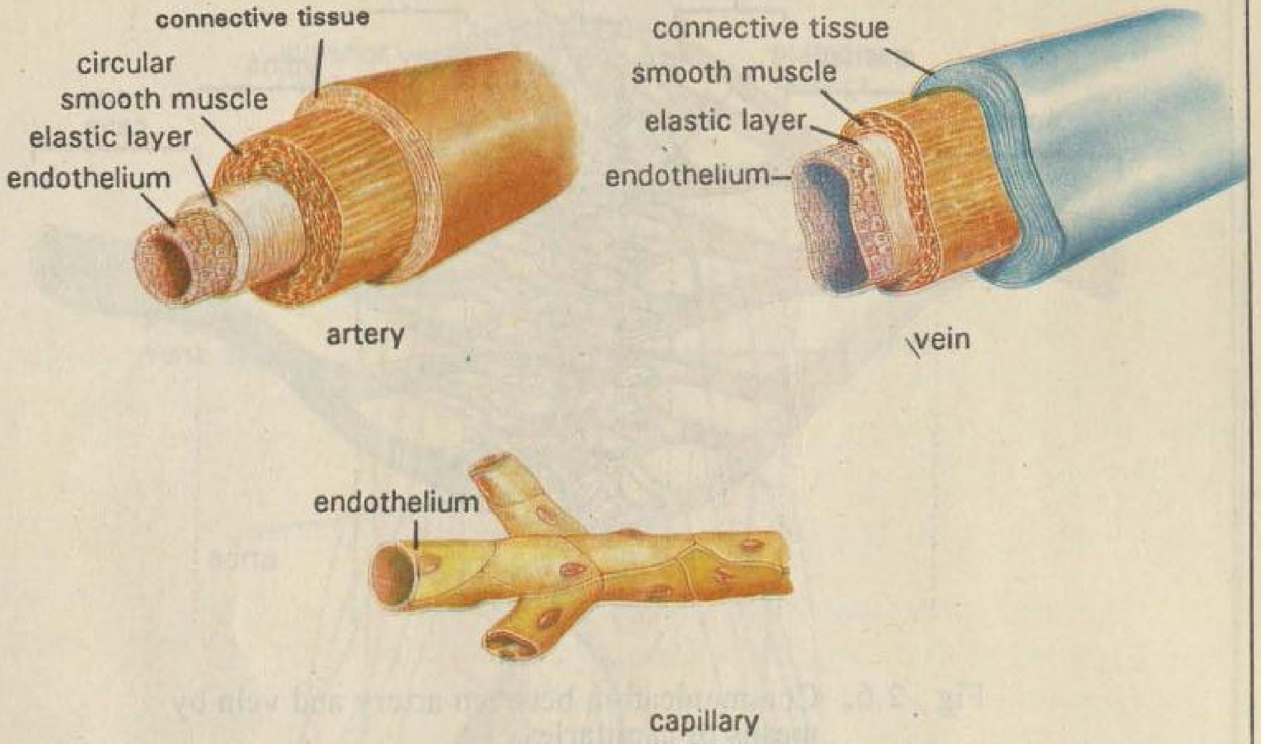

connective tissue
circular smooth muscle
elastic layer
endothelium
artery
connective tissue
smooth muscle
elastic layer
endothelium
vein
endothelium
capillary

Fig 2.5. The Structure of blood vessels

arteries, which may be called **arterioles**, are about 0.2 mm in diameter. Arteries have thick, muscular, elastic walls which are essentially made up of three layers: the outer layer consisting of a thick coat of fibrous connective tissue; the middle layer made up of smooth muscles and elastic tissue, and the inner lining, the endothelium (Fig 2.5). All arteries carry oxygenated blood except the pulmonary arteries which carry deoxygenated blood.

Capillaries are the microscopic blood vessels which are only one cell thick and basically consist of a single layer of endothelial cells. In the tissues the arterioles form a branching network of capillaries and their concentration is highest in the metabolically most active regions. The average diameter of a capillary is about 7 μm. Therefore, the exchange of nutrients, waste products and regulatory substances such as hormones occurs between the blood of the capillaries and the various cells and tissues by the process of diffusion and active transport. Normally, when the concentration of oxygen and nutrients in the capillary blood is greater than in the surrounding cells, the movement of these substances out of the blood and into the cells takes place. Similarly,

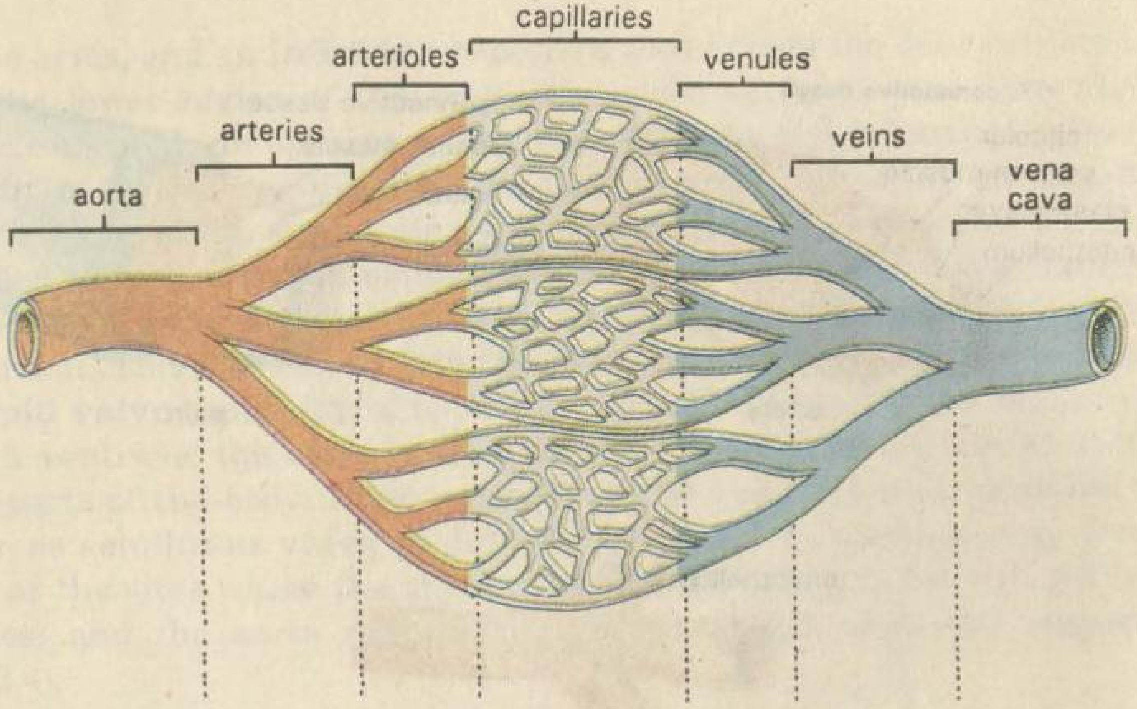


Fig 2.6. Communication between artery and vein by means of capillaries

the concentration of metabolic wastes such as carbon dioxide in the surrounding cells may be greater than that of the capillary blood, resulting in the movements of these substances into the blood stream. The time lapse in flow of blood from the arterioles to the first small veins is enough for the exchange to take place through the capillaries (Fig. 2.6).

Veins: Blood flows from the capillaries into small veins, and from these into the larger veins that carry the blood to the heart. The veins are comparatively thin walled than the arteries, although they are composed of the same layers, but the middle layer is much thinner and less developed and there is no inner elastic membrane. To facilitate the flow of blood in the veins internal valves are present in several veins especially those of the abdomen and hind limbs though other factors such as movement of the body, breathing movements and the pressure of blood are also important

The Arterial Pathway

The aorta which arises from the left ventricle gives off its first pair of branches known as **coronary arteries** to the heart itself. These arteries are extremely important in providing oxygen and food to the heart muscles. The aorta then forms an arch and before it descends down,it gives three arteries

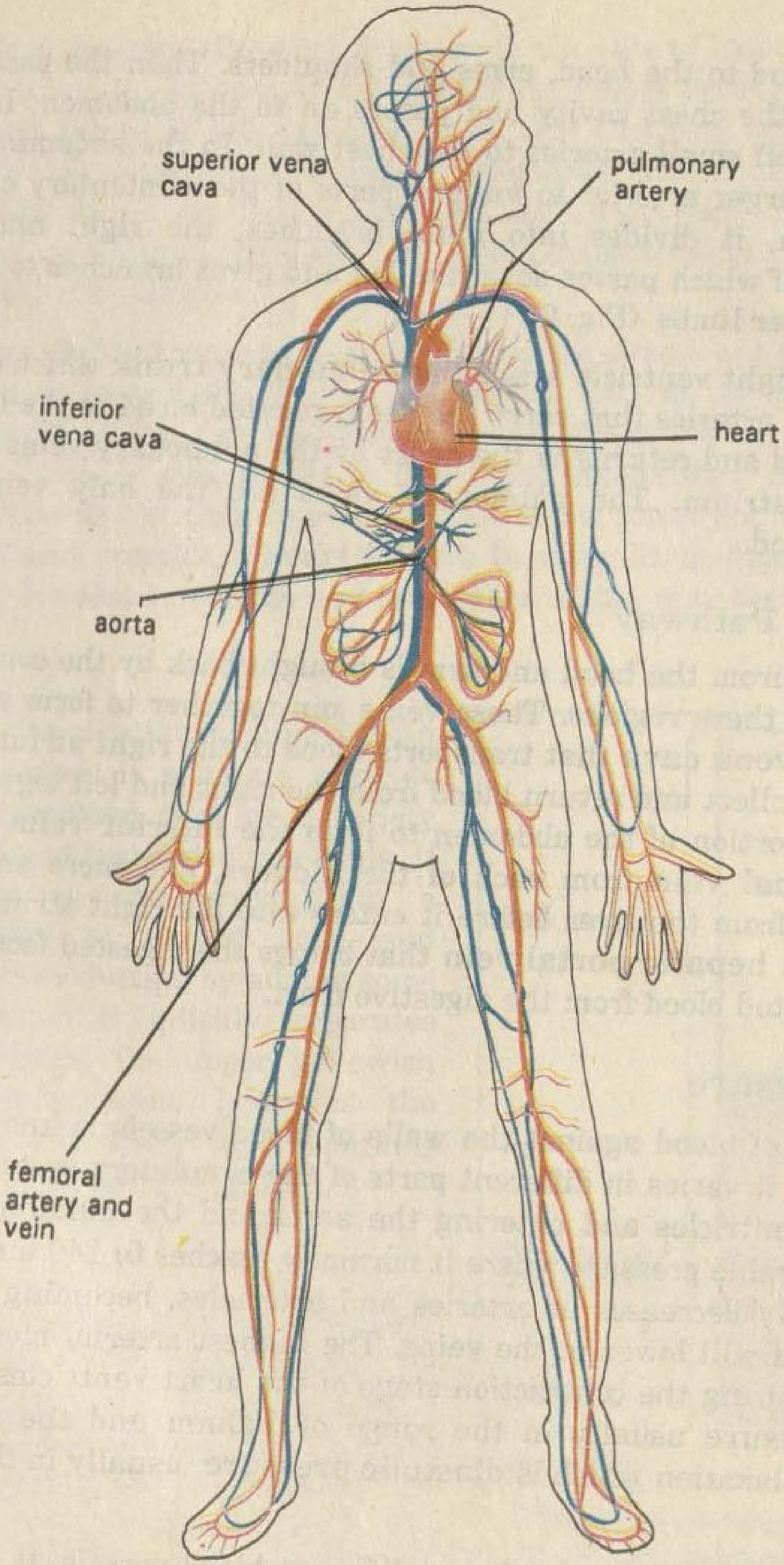

superior vena cava
pulmonary artery
inferior vena cava
heart
aorta
femoral artery and vein

Fig 2.7. The main arteries and veins in the human circulatory system

that supply blood to the head, arms and shoulders. Then the aorta descends down through the chest cavity and passes on to the abdomen. In the chest cavity it gives off small arteries to the chest wall. In the abdominal region it gives several larger arteries to various parts of the alimentary canal at the lower abdomen, it divides into main branches, the right and left **iliac arteries** each of which passes down the leg and gives branches to the various parts of the lower limbs (Fig. 2.7)

From the right ventricle arises the **pulmonary trunk** which divides into two pulmonary arteries that carry the deoxygenated blood to the lungs where it is oxygenated and returns to the heart by the pulmonary veins which open into the left atrium. The pulmonary veins are the only veins carrying oxygenated blood.

The Venous Pathway

The blood from the head and arm is brought back by the counterparts of the arteries of these regions. These veins join together to form a large vein, the **superior vena cava** that transports blood to the right atrium. The right and left iliac collect and return blood from the right and left legs. They unite in the lower portion of the abdomen to form the **inferior vena cava** which receives a **renal vein** from each of the kidneys, and more anteriorly the **hepatic vein** from the liver before it enters into the right atrium. The liver also receives a **hepatic portal vein** that brings the digested food along with the deoxygenated blood from the digestive tract.

Blood Pressure

The force of blood against the walls of blood vessels is known as **blood pressure** and it varies in different parts of the circulatory system. The blood leaving the ventricles and entering the aorta and the pulmonary artery is under considerable pressure where it normally reaches to 140 mm of mercury. It progressively decreases in arteries and arterioles, becoming lower in the capillaries and still lower in the veins. The highest arterial blood pressure is experienced during the contraction stage of the heart ventricles and is called **systolic pressure** usually in the range of 120mm and the lowest at the ventricular relaxation which is **diastolic pressure**, usually in the range of 70 to 85mm.

The rate of blood flow varies in different blood vessels. It is high in the aorta (about 400 to 500mm per second), decreasing along the arterial system, becoming greatly reduced in the capillaries (about 150mm per second). The main reason for this is that cross-sectional area of the capillaries is greater than the large arteries, therefore decrease in the rate of blood-flow. Since the transfer of nutrients, hormones and metabolic wastes between the blood and tissues occurs solely at the capillary level, the slow rate of blood flow is of advantage in allowing adequate time for exchange. The smaller veins formed by the joining of the capillaries and then the larger veins formed from the latter have an overall decrease in total cross-sectional area, therefore increased rate of blood flow.

The flow of blood also varies according to the conditions such as exercise, after eating and when the body is hot or cold. It also varies from organ to organ depending upon the needs of the body but at the same time a fairly steady blood flow is maintained to important organs such as brain and the heart itself. Some disturbance of blood flow to the brain may cause a **stroke**, and to the heart muscles, a **heart attack**. In other parts, blood vessels in one region may increase in volume and in another region may decrease in volume.

Blood

Blood, the circulatory fluid within the blood vessels is a highly complex substance composed of a large variety of dissolved and suspended materials. If some blood is transferred from a person's vein to a test tube and prevented from clotting by adding some anticoagulants, it quickly separates into two layers: the upper yellowish and semi-transparent layer is the plasma and the lower layer contains mainly the blood cells (Fig. 2.8).

Plasma

It is the liquid part of the blood and constitutes about 55 percent by volume of the blood. It is mainly water (90% by weight of the plasma) with a large number of inorganic and organic substances dissolved in it .7% to 8% of the plasma is made by different types of proteins which have several roles to play. For example, inorganic iron is bound to a special type of protein and provides the means of

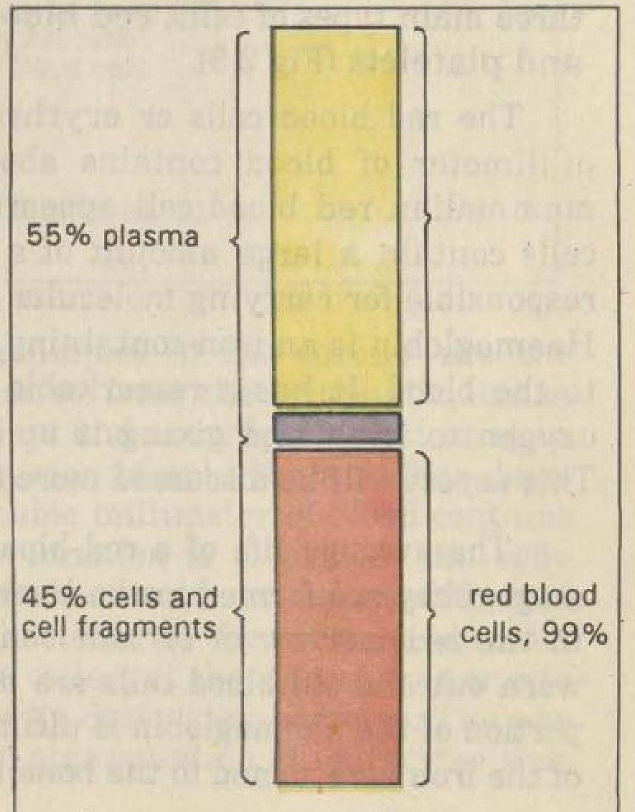


Fig 2.8.
Volume relationship of plasma and blood cells in human blood

transporting the iron in the body to the various places. Some other proteins are responsible for maintaining the osmotic pressure between the blood stream and the surrounding medium. A special type of blood protein known as **fibrinogen** helps in blood clotting. Some of them, commonly known as **antibodies** provide immunity against certain diseases. The other two important constituents are the salts and sugars. Salts constitute about 0.9 percent, of which sodium chloride and calcium ions are predominent, while potassium and magnesium ions are in lesser quantities. Simple sugars, of which glucose is more important, constitute about 0.1 percent. The remaining 2 to 3 percent of the plasma is made up of a variety of substances including products of digestion (amino-acids, fatty acids); hormones and metabolic wastes (urea, uric acid, carbon dioxide), but there are many other dissolved materials in this remarkable fluid.

Blood cells

The blood cells make up the remaining 45 per cent of the blood. There are three main types of cells, **red blood cells, (R.B.C) white blood cells (W.B.C) and platelets** (Fig 2.9).

The red blood cells or **erythrocytes** are the most numerous, one cubic millimeter of blood contains about five million of them. The human or mammalian red blood cell appears biconcave and without a nucleus. These cells contain a large amount of a protein known as **haemoglobin** which is responsible for carrying molecular oxygen to all cells and tissues of the body. Haemoglobin is an iron-containing, pigmented compound that gives red colour to the blood. It has a remarkable property of attaching dissolved molecular oxygen to itself and giving it up again where oxygen concentration is low. This aspect will be discussed more fully in respiration.

The average life of a red blood cell is about 120 days. In the embryonic stages they are formed in the liver and spleen but after birth they are formed in the red marrow of certain bones such as the ribs and breast-bones. The worn out and old blood cells are destroyed chiefly in the spleen and liver. A portion of the haemoglobin is ultimately converted into bile pigment and most of the iron is returned to the bone marrow.

The white blood cells or **leucocytes** are colourless, containing a nucleus and majority of them are larger than the red blood cells or erythrocytes. They are of several types and are classified on the basis of structural differences into two groups: (1) those with a single nucleus and a clear cytoplasm and (2) those having an incompletely partitioned nucleus and a functional

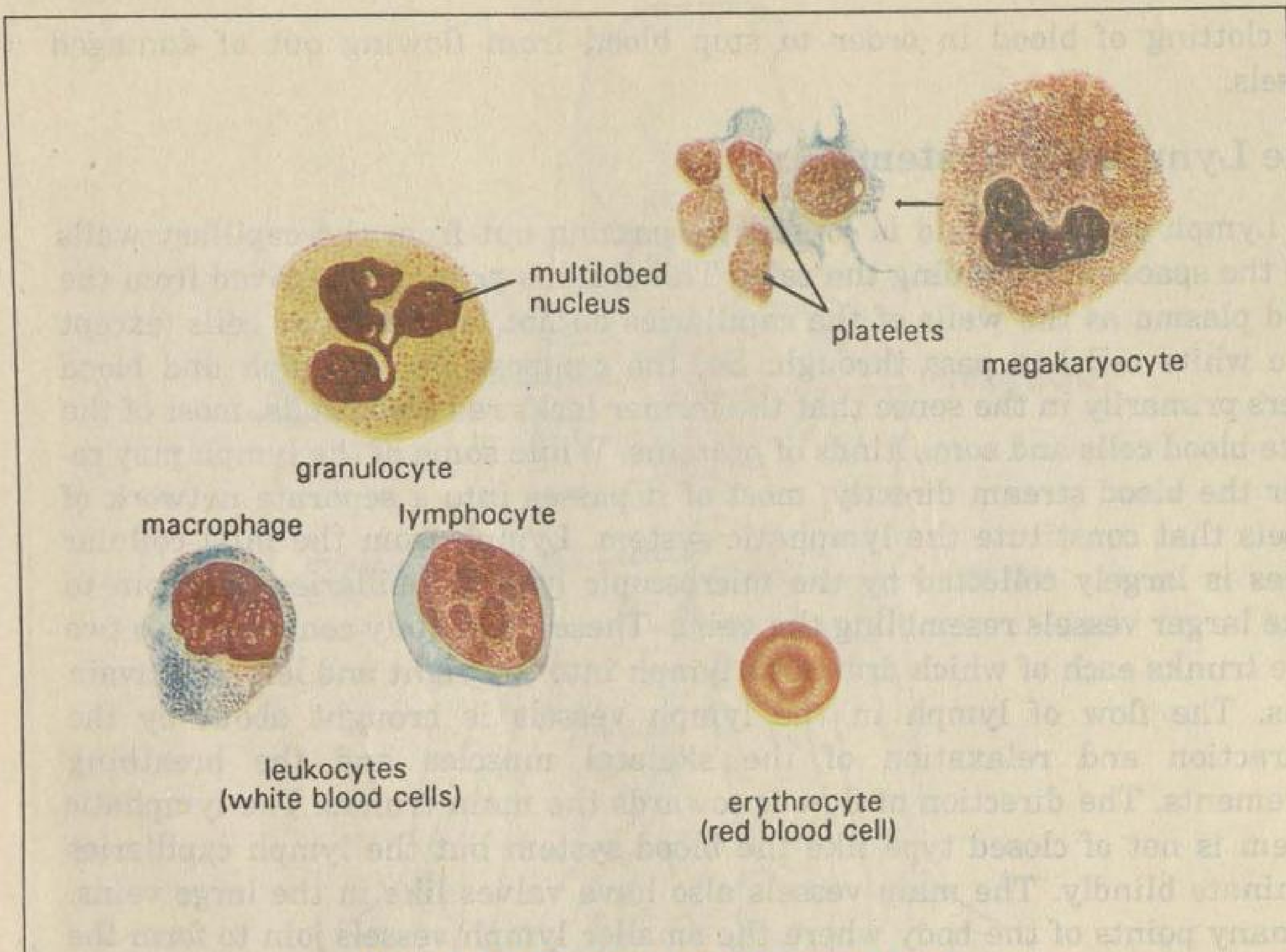

multilobed nucleus
platelets
megakaryocyte
granulocyte
macrophage
lymphocyte
leukocytes (white blood cells)
erythrocyte (red blood cell)

Fig 2.9. Composition of human blood

cytoplasm containing fine granules. The examples of the former are the lymphocytes and monocytes both of which arise from the lymphatic tissue. The examples of the second group are basophils and neutrophils that arise in the red bone marrow. They have a short life span of only three to four days. White cells are much less in number and a cubic millimeter of blood contains only 7,000 to 8,000 of them. Their primary function is to protect the body against invading micro-organisms. Some of them such as neutrophils and monocytes engulf foreign particles, such as bacteria, by forming pseudopodia around them. These and other leucocytes also collect at the wound area or site of infection. They help to combat the disease by destroying bacteria. The pus that forms in an infected wound is largely an accumulation of leucocytes that have died in fighting against bacteria.

Blood platelets are much smaller than either red blood cells or white blood cells. As a matter of fact they are small, oval fragments of specialised bone marrow cells and are without nucleus. They play an important role in the clotting of blood in order to stop blood from flowing out of damaged vessels.

The Lymphatic System

Lymph or tissue fluid is constantly passing out from the capillary walls into the spaces surrounding the cells. This fluid is primarily derived from the blood plasma as the walls of the capillaries do not let the blood cells (except some white cells) to pass through. So, the composition of lymph and blood differs primarily in the sense that the former lacks red blood cells, most of the white blood cells and some kinds of proteins. While some of the lymph may re-enter the blood stream directly, most of it passes into a separate network of vessels that constitute the lymphatic system. Lymph from the inter-cellular spaces is largely collected by the microscopic lymph capillaries that join to make larger vessels resembling the veins. These ultimately converge into two large trunks each of which drains its lymph into the right and left subclavain veins. The flow of lymph in the lymph vessels is brought about by the contraction and relaxation of the skeletal muscles and the breathing movements. The direction of flow is towards the main trunks. The lymphatic system is not of closed type like the blood system but the lymph capillaries terminate blindly. The main vessels also have valves like in the large veins. At many points of the body where the smaller lymph vessels join to form the larger ones, there are special aggregation of cells forming lumpy masses called **lymph nodes**. These are present at various parts of the body, especially in the neck, near the arm pits and in the groin area. These nodes play an important role in the body's defences against disease by producing lymphocytes and antibodies. During infection, the lymph nodes may swell in the process of filtering out bacteria and other foreign bodies from the lymph (Fig 2.10).

The main function of lymph is to bathe the tissues and keep them moist but owing to the greater permeability of lymph vessels than the blood vessels, large protein molecules and fats are also transported and returned to the blood stream. In addition, lymph nodes serve to remove micro-organisms as well as cancer cells which may have broken loose from other tissues and entered the lymph vessels.

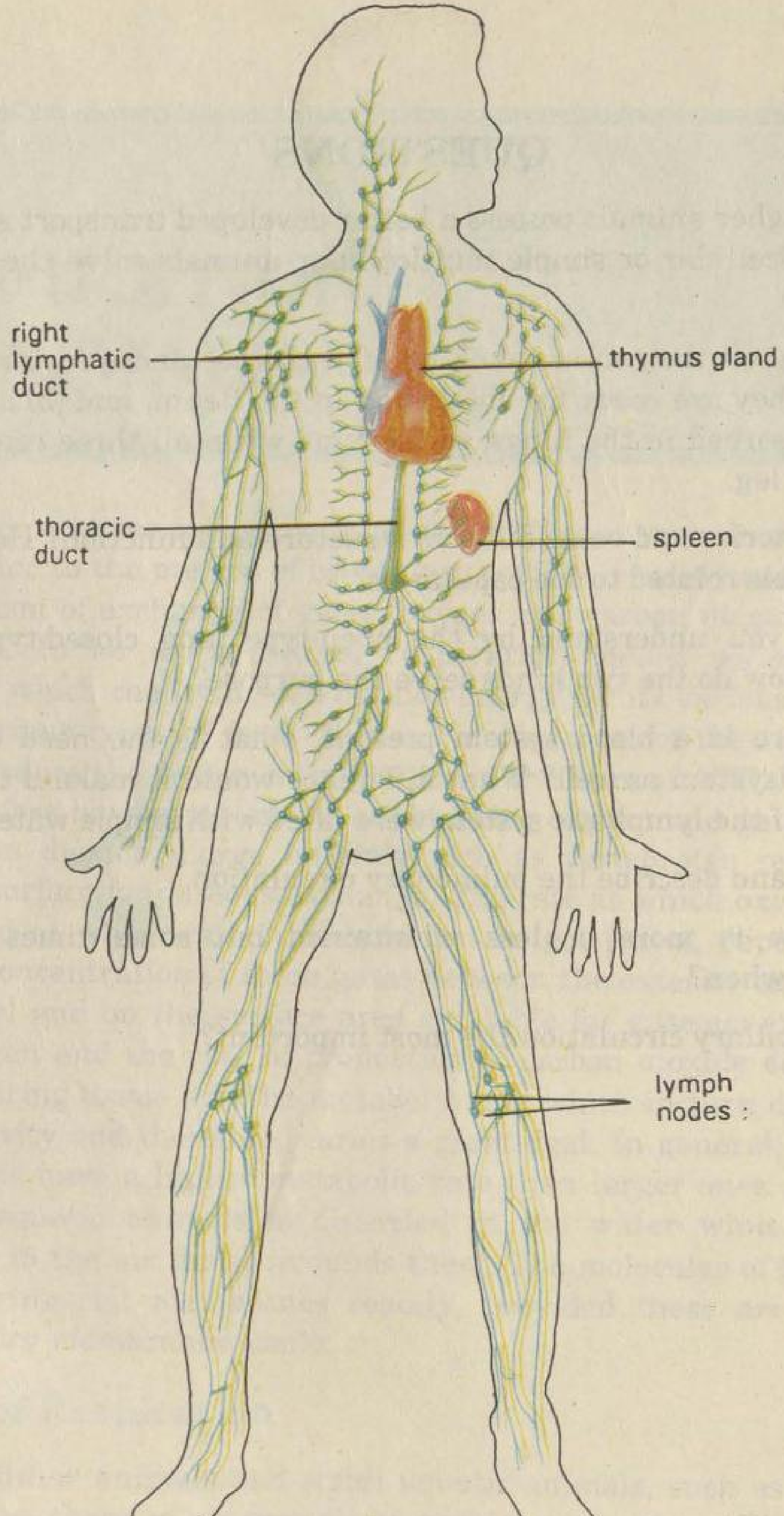

right lymphatic duct
thymus gland
thoracic duct
spleen
lymph nodes

Fig 2.10. The human lymphatic system.

QUESTIONS

1. Why do higher animals possess a better developed transport system? How do the unicellular or simple multicellular animals solve the problems of transport?
2. State in detail the course taken by (a) a glucose and a fat molecule from the time they are ready for absorption in the ileum, and (b) a molecule of oxygen absorbed in the lungs, to the time when all three reach a muscle cell in the leg.
3. How do arteries and veins differ in structure and function? How are these blood vessels related to the capillaries?
4. What do you understand by the open-type' and closed-type' of blood system? How do the two kinds serve the purpose?
5. When there is a blood system present, what is the need of having a lymphatic system as well? What difference would it make if there was no lymph or if the lymphatic system were filled with simple water?
6. Illustrate and describe the pulmonary circulation.
7. Blood flow is more or less maintained but some times it changes suddenly, when?
8. Why is capillary circulation the most important?

RESPIRATION IN ANIMALS

3

The term respiration has been used in different meanings in Biology. It may be applied to the process of breathing, namely inhaling and exhaling and the mechanism of exchange of gases, oxygen and carbon dioxide, involved in this process. To be more precise, **respiration** means series of chemical processes by which the living cell obtains energy for its various life functions from the various types of food. This is because most of the organisms need oxygen to produce the energy from glucose in the form of ATP. Respiring cells should therefore have some means of obtaining oxygen and getting rid of the excess carbon dioxide. Large animals such as vertebrates require a large respiratory surface for gaseous exchange. The rate at which oxygen can enter the body and at which carbon dioxide can be got rid of, depends upon the gradient of concentration of these gases between the exterior and the interior of the animal and on the surface area available for gaseous exchange . The need of oxygen and the rate of production of carbon dioxide depends on the mass of respiring tissue and the metabolic rate which in turn depends on the physical activity and therefore, varies a great deal. In general, it seems that small animals have a higher metabolic rate than larger ones. The supply of oxygen for aquatic animals is dissovled in the water while for the land animals it is in the air that surrounds them. The molecules of both the gases can cross living cell membranes readily, provided these are moist; gases cannot pass dry membranes easily.

Methods of Respiration

In unicellular animals and small aquatic animals, such as coelenterates and flatworms, there is no specialized respiratory system. The exchange of oxygen and carbon dioxide is carried out directly by diffusion. In the more complex animals, this method can no longer suitably fulfil the needs of the body cells. Therefore, several different types of respiratory systems are found in them. Two basic features, however, are common among them: there must be transportation system which is essentially the blood vascular system, and there must be an extensive but thin epithelial surface that should permit a rapid entry of oxygen into the blood system and rapid elimination of carbon dioxide at the same time.

Respiration in *Hydra*

As mentioned above, there are no specialized organs for respiration in coelenterates, the gaseous exchange therefore, takes place through the whole surface of the body wherever it is in contact with water. Oxygen also diffuses from the water in the digestive cavity into the adjacent cells. The surface lining of the coelenteron, therefore, provides efficiency in this process.

Respiration in a Planarian

As in coelenterates, the gaseous exchange is carried out over the whole surface. Planarian being a free-living animal is fairly active and requires a continued supply of oxygen. As its external surface is large relative to the size of the body, the required amount of oxygen is thus easily obtained.

Respiration in Earthworm

Although, earthworm is of higher organization than *Hydra* and *Planaria*, yet it does not have any special respiratory organs. The gaseous exchange takes place mainly through the skin which is richly supplied by blood capillaries and is always kept moist by the secretion of the epidermal mucous gland cells and also by the coelomic fluid passing out through the dorsal pores. Oxygen in solution passes through the cuticle and epidermis into the blood where it combines with the haemoglobin to form oxyhaemoglobin, which gives up the oxygen to tissues where O_2 concentration is low. The blood does not come into direct contact with the tissue cells so that oxygen must be handed over through the tissue fluids, coelomic fluid, etc. Carbon dioxide is removed from the tissues by the blood and carried in solution in the plasma to the skin, where it is excreted.

Respiration in Grasshopper

The insects have evolved quite a different way of carrying oxygen and carbon dioxide to and from their cells. This is done directly by a branching system of air tubes called **tracheae**. The main tracheal trunks communicate with the exterior by paired apertures called **spiracles** present on the sides of the body. There are ten pairs of them, two in the thorax and one pair in each of the first eight abdominal segments. The main tracheae divide and subdivide, ultimately forming very fine tubes called **tracheoles.** These tracheoles form a sort of end cell, partly filled with fluid in which the oxygen dissolves. These tracheoles surround the organs and tissues and continuously supply oxygen to the living cells directly. A concentration gradient is set up between them and the spiracular openings and oxygen will diffuse into the tracheae from the outside air. The movement of air through the tracheal trunks is facilitated by respiratory movements of contraction and expansion of the abdomen. Carbon dioxide collected from the tissues directly by the air-tubes, passes out through the spiracles but some carbon dioxide dissolves in the "blood" and then passes out through the cuticle especially through the thinner regions which are permeable to gases and allow the carbon dioxide to pass through it (Fig. 3.1).

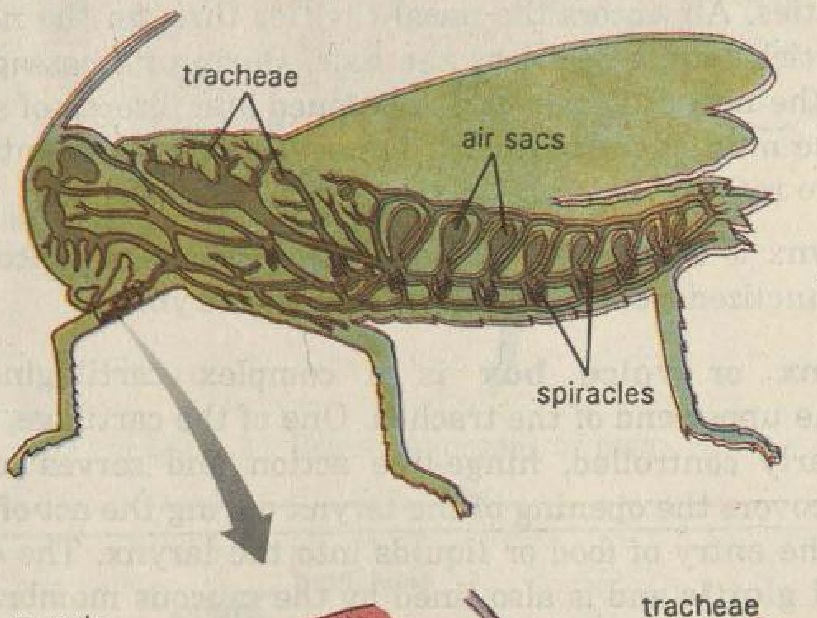


Fig 3.1. A diagrammatic sketch of breathing mechanism in grasshopper.

Respiration in Man

Man, like other large and complex animals, requires for his respiratory needs a source of oxygen, a respiratory surface of large area, a current of air over the respiratory surface, a respiratory medium (blood), a respiratory pigment (haemoglobin) and a means of carrying more carbon dioxide than is possible by mere physical solution. All these points need to be discussed in detail. In man and other mammals, the respiratory system includes the lungs and air passage which lead to them.

Air Passage Ways

These consist of nose, pharynx, trachea, bronchi and bronchioles. The nose has two nasal cavities, each of which is lined internally with mucous membrane, consisting largely of ciliated epithelial cells and is subdivided into three passage ways by the projection of several bones from the lateral walls of the nasal cavities. Air enters the nasal cavities through the nostrils and the large dust particles are trapped by the hair. During its passage through the upper part of the nose it is warmed, moistened and filtered of smaller foreign particles by the mucous membrane. The nasal cavities lead into the throat or pharynx by two internal openings.

The pharynx is a muscular passage, also lined with mucous membrane. The air is channelized from the pharynx into the larynx.

The **larynx** or **voice box** is a complex cartilaginous structure surrounding the upper end of the trachea. One of the cartilage, the **epiglottis** has a muscularly controlled, hinge-like action and serves as a lid which automatically covers the opening of the larynx during the act of swallowing so as to prevent the entry of food or liquids into the larynx. The opening of the larynx is called **glottis** and is also lined by the mucous membrane. Stretched across it there are two thin-edge fibrous bands, called **vocal cords**, that help in voice production.

The **trachea** or **windpipe** is tubular structure lying ventral to the oesophagus and extends to the chest cavity or thorax where it is divided into right and left bronchi. The tracheal wall contains a series of C-shaped cartilage rings which prevent trachea from collapsing and thus maintaining an open passage way for the air.

Each **bronchus** on entering the lung divides and subdivides progressively into smaller and smaller bronchi. When the smaller bronchi attain a diameter of 1 mm or less, then they are called **bronchioles**. The

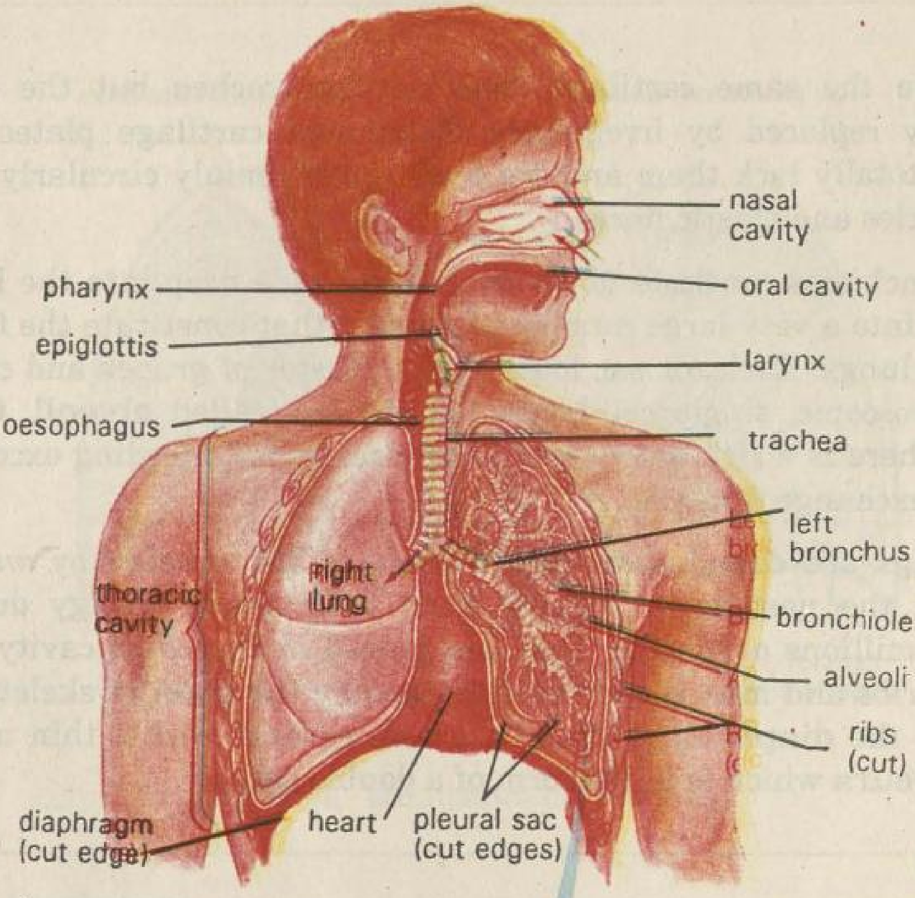

nasal cavity
pharynx
oral cavity
epiglottis
larynx
oesophagus
trachea
left bronchus
right lung
thoracic cavity
bronchiole
alveoli
ribs (cut)
diaphragm (cut edge)
heart
pleural sac (cut edges)

Fig 3.2. Breathing organs of man.

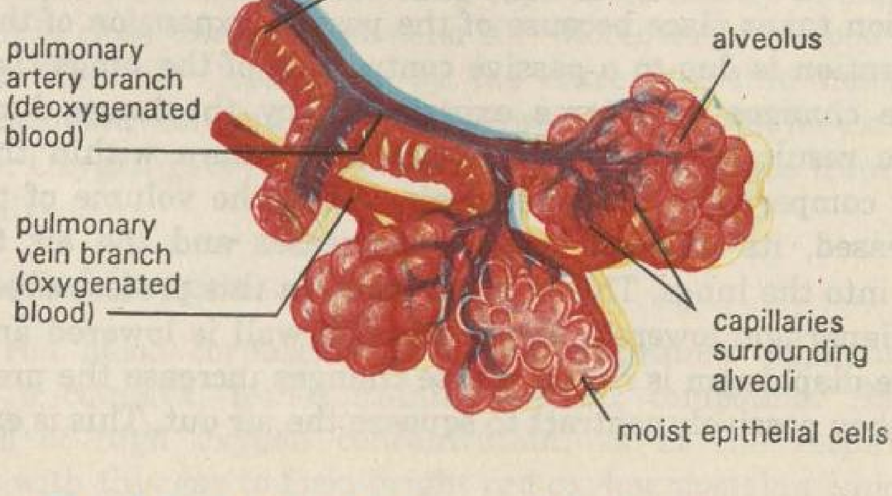

bronchiole
alveolus
pulmonary artery branch (deoxygenated blood)
pulmonary vein branch (oxygenated blood)
capillaries surrounding alveoli
moist epithelial cells

Fig 3.3. Relationship between blood capillaries and air-sacs.

bronchi have the same cartilage rings as the trachea but the rings are progressively replaced by irregularly distributed cartilage plates and the bronchioles totally lack them and are made up of mainly circularly arranged smooth muscles and elastic fibres.

The bronchioles continue to divide and subivide deep into the lungs and finally open into a very large number of air sacs that constitute the functional units of the lungs. Each air sac looks like a cluster of grapes and consists of several microscopic, single cell-layered structures called **alveoli**. Overlying the alveoli there is a rich network of blood capillaries affording excellent site for gaseous exchange (Fig 3.3).

The lungs are closed sacs that connect to the outside by way of the trachea and the nostrils or mouth. Each lung seems spongy due to the presence of millions of alveoli. They are placed in the chest cavity which is bounded by ribs and muscles on the sides and by the sheet of skeletal muscle below called the **diaphragm**. Both lungs are covered with a thin membrane called the **pleura** which is in the form of a double sac.

Breathing

The events concerned with pumping air in and out of the lungs constitute breathing, which is therefore a mechanical process and consists of two phases, the taking in of air, called **inspiration**, and letting out of air, called **expiration**. Under resting conditions the two phases occur rhythmically at a frequency of 15 to 20 times per minute in the adult human. The lungs themselves neither draw in air not push it out. It is the chest wall and the diaphragm that act as a large pump for moving the air in and out of the lungs. Inspiration takes place because of the passive expansion of the elastic lungs and expiration is due to a passive contraction of the lungs that follow expansion. The changes in volume experienced by the lungs during this process are the result of alternate changes in pressure within the closed thoracic cavity compared to the outside air. When the volume of the chest cavity is increased, its internal pressure decreases and the air from the outside rushes into the lungs. This is inspiration. In this process chest wall is elevated and diaphragm lowered. Then the chest wall is lowered and moves inward, and the diaphragm is raised. These changes increase the pressure on the lungs and they passively contract to squeeze the air out. This is expiration (Fig. 3.4).

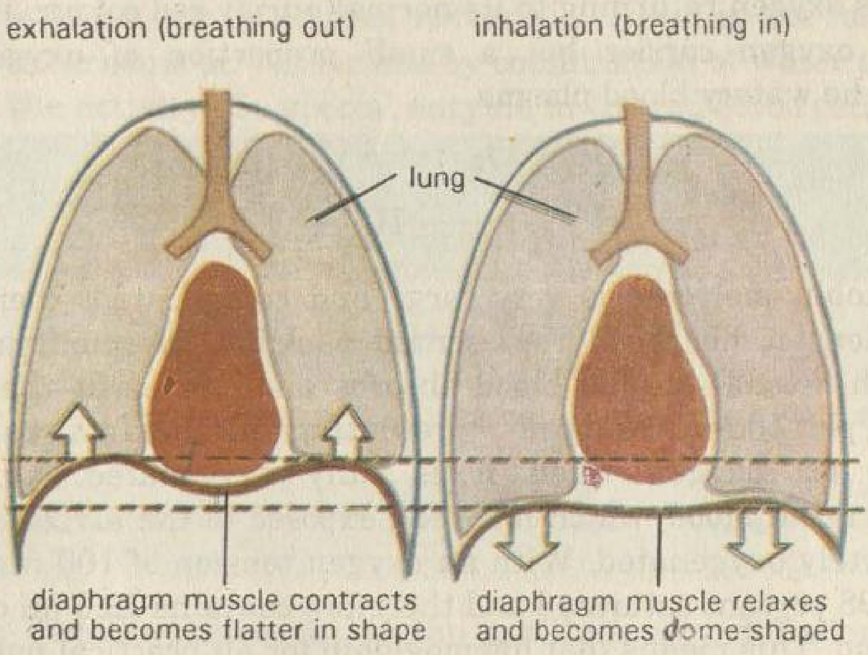

exhalation (breathing out)
inhalation (breathing in)
lung
diaphragm muscle contracts and becomes flatter in shape
diaphragm muscle relaxes and becomes dome-shaped

Fig 3.4. Mechanism of breathing

Gaseous Exchange

The intake of oxygen and release of carbon dioxide by blood passing through the capillaries of the alveoli is brought about by diffusion based on differences in the partial pressure of these gases. Within the rich network of capillaries surrounding the alveoli, blood is distributed in extremely thin layers and therefore exposed to large alveolar surface. It also seems that the red blood cells pass through the lung capillaries mostly in single file so that cells come in close contact to alveolar air. Moreover, the blood in the lungs is separated from the alveolar air by the extremely thin membranes of the capillaries and alveoli and all these factors contribute in an extensive gaseous exchange. Oxygen gets into the blood and carbon dioxide from the blood gets into the alveoli.

Transport of Oxygen

The red blood corpuscles have the respiratory pigment haemoglobin which is a complex, iron-containing organic compound. Haemoglobin, in conditions of high oxygen concentration, as at the respiratory surface, combines with this gas to form bright red oxyhaemoglobin which is rather an unstable compound. In situations of low oxygen concentration, as in the deoxygenated tissues where carbon dioxide has accumulated, it readily gives up most of its oxygen returning to its normal purply-red colour. It thus acts as an efficient oxygen carrier but a small proportion of oxygen also gets dissolved in the watery blood plasma.

$$Hb + O_2 \longrightarrow HbO_2$$

$$HbO_2 \longrightarrow Hb + O_2$$

Haemoglobin molecule is very large and complicated, therefore in the above equations it has been represented as Hb. The maximal amount of oxygen which normal human blood absorbs and carries at the sea level is about 20 ml per 100 ml of blood representing the maximal capacity of the haemoglobin for oxygen when it is fully oxygenated. Under normal conditions, arterial blood, which has been exposed to the alveoli of the lungs, is not completely oxygenated. With an oxygen tension of 100 mm of mercury it is usually 98 percent saturated and therefore contains 19.6 ml of oxygen per 100 ml of blood. This means that haemoglobin for all practical purposes can be almost completely oxygenated by an oxygen pressure of 100 mm mercury which is the same as that in the lungs. Any higher oxygen pressure would have the same result. When the oxygen pressure falls below 60 mm mercury, as is the case in many of the cells and tissues where oxygen has been consumed, the oxygen saturation of haemoglobin decreases very sharply. This results in the liberation of relatively large quantities of oxygen from the haemoglobin. Thus in the passage of blood through tissues where oxygen tension is low, rapid dissociation of oxyhaemoglobin occurs. Two important factors affect the capacity of haemoglobin to combine with oxygen: carbon dioxide or hydrogen ion concentration and temperature. With the increasing carbon dioxide pressure, oxygen tension decreases and so does the quantity of oxygen that haemoglobin will hold. It means that increased carbon dioxide tension favours the greater liberation of oxygen from the blood to the tissues. Similarly, rise in temperature also causes a decrease in the oxygen-carrying capacity of blood, as for example, in increased muscular activity.

Transport of Carbon Dioxide

Carbon dioxide is transported in the blood in several different states. This gas is more soluble than oxygen and some of it dissolves freely in the tissue fluid surrounding the cells and this passes to the plasma within the blood capillaries. Some of it travels in combination with the amino-groups of the haemoglobin and other blood proteins but most of it is carried as bicarbonate ion which is combined with sodium in the plasma and with potassium within the corpuscles. All the reactions in which carbon dioxide combines with substances in the blood are, of course, reversible. Towards the formation of bicarbonates, first carbonic acid is formed by combination of water and carbon dioxide through the activity of a special enzyme in the red blood cells:

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

The carbonic acid then ionizes to form hydrogen ions and bicarbonate ions:

$$H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

When these bicarbonates reach the lung capillaries the reverse reactions occur:

$$HCO_3^- + H^+ \longrightarrow H_2CO_3 \longrightarrow H_2O + CO_2$$

This carbon dioxide passes out of the capillaries by diffusion into the alveoli from which it is exhaled. It has been found that arterial blood contains about 50 ml of carbon dioxide per 100 ml of blood, whereas venous blood has 54 ml per 100 ml. Therefore, each 100 ml of blood as it passes through the tissues takes up 4 ml of carbon dioxide and in time gives off 4 ml of CO_2 per 100 ml of blood as it passes through the lungs.

Energy Production

The oxidation-reduction processes resulting in the release of energy take place in the tissues themselves and are called **tissue respiration**. This release of energy is the result of a complex chain of chemical reactions, each of which is catalysed by a special respiratory enzyme within the cells and this has already been discussed earlier. In many instances the chemical compound or substrate is glucose itself but fatty acids and amino-acids may be used as well.

In the laboratory, glucose can be burnt to give carbon dioxide and water with the release of energy as:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

But in the cells, the glucose is in dilute aqueous solution and such a straight forward oxidation by atmospheric oxygen is impossible. Furthermore, the oxidation must take place at the relatively low temperature of the body, therefore, tissue respiration must not be thought of as the direct oxidation of the substrate by oxygen. It must be noted that respiration is a very complicated series of chemical reactions, each catalysed by a particular enzyme resulting in formation of the molecules of a compound called **adenosine triphosphate (ATP)**. This contains energy-rich bonds which are synthesized step-wise and then provide a source of energy which is released when they break down to form **adenosine diphosphate** (ADP) and free phosphate, both of which are then available for resynthesis into ATP. By having ATP distributed in the cells energy is always immediately available for protein synthesis and movement, etc.

QUESTIONS

1. What is the composition of inhaled and exhaled air?
2. What is the rate of breathing at rest and during heavy exercise? Why is this change effected?
3. What are the various properties of respiratory surface of different animals?
4. Explain the mechanical aspects of breathing in man.
5. What is cellular respiration and how is it brought about?
6. Enumerate differences of breathing in earthworm and insect.
7. Explain about the role of haemoglobin in the transport of oxygen and carbon dioxide.

EXCRETION AND HOMEOSTASIS IN ANIMALS

4

Several chemical changes take place in the cells due to which some wastes or by-products are also formed. The important ones of these are the carbon dioxide and nitrogenous materials. For the most part, the cell has little chemical use for carbon dioxide and very often water is also produced in excess. Similarly either ammonia, urea or uric acid is the predominent nitrogenous excretory substance formed and these are all toxic or poisonous to a greater or lesser extent and must be removed promptly. Ammonia is the major and immediate nitrogenous product of protein and amino-acid metabolism for all organisms. It is easily diffusable and can be removed as such. Most of the aquatic animals excrete ammonia although it is the most toxic but they have vast environmental reservoir of water into which they can release waste ammonia without fear of self-intoxication. On the other hand, where there is a limited environmental supply of water accompanied with larger body size, ammonia could not be disposed off fast enough from the body to avoid toxic effects. Thus, it is converted to uric acid which is insoluble and comparatively harmless. Animals which live in between the two extreme conditions usually excrete urea. Excretion may therefore be defined as the removal of the above mentioned or any other substances which are not needed in the cell activities.

Excretion in *Hydra*

There are no definite organs of respiration or of nitrogenous excretion, so it seems evident that respiration as well as the excretion of waste nitrogenous matter takes place over the whole surface of the body wherever it is in contact with the water. Therefore, removal of carbon dioxide, salts and nitrogenous wastes (mainly ammonia) takes place by diffusion. But it must be remembered that water continuously enters the animal, faster than it diffuses out. This is because a large surface is presented to water, both by the ectoderm and endoderm. The mechanism by which the surplus water is removed is not fully known but it must require the expenditure of energy. The cells of *Hydra* do osmoregulate because they have a lower concentration of water than does the surrounding pond.

Excretion in a Planarian

In flat worms such as *Planaria* excretion occurs by diffusion as well as by a specialised excretory system. This system consists of a series of branching tubes or ducts the outer ends of which end up in **flame cells or flame bulbs.** Each flame cell has the cytoplasmic body with some cytoplasmic prolongations. The cytoplasm is hollowed out to form a large cavity which is continuous with that of the finer tubules and because of this the nucleus is displaced. A bunch of flagella hangs down into the cavity of the cells and its flickering movement gives the flame cell its name. It seems probable that soluble excretory products such as carbon dioxide, salts and ammonia diffuse from the surrounding tissues into the lumen of the flame cells and the function of the flagella is to keep the fluid circulating in the tubule. It is also thought that the flagella cause a sufficient suction pressure to draw the fluid into the lumen from the surrounding parenchyma. The waste material is removed to the outside by the excretory pores. Since water keeps entering the body, the excretory system also acts as osmoregulatory in function and removes the excess water (Fig. 4.1).

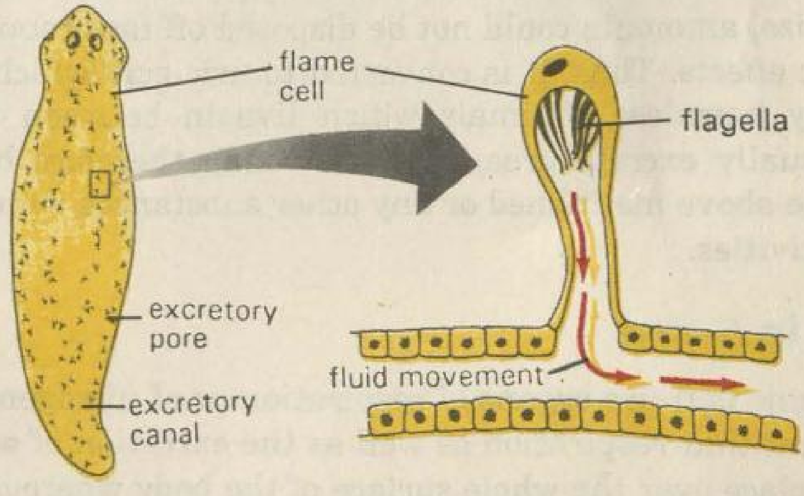


Fig 4.1. Excretory ducts and flame cell of planaria

Excretion in Earthworm

In earthworm the principal means of excretion is by specialised organs, the **nephridia**, which are segmentally arranged (Fig. 4.2). A typical nephridium opens into the coelom by a ciliated funnel or **nephrostome** from where it takes the form of a tube which loops about in a complicated way before opening to the exterior by the **nephridiopore**. The nephrostome is in the form of a ciliated funnel whose upper wall is much larger than the lower wall while the side walls are composed of ciliated cells which are similar in nature and continuous with the cells of the narrow tube. The waste substances which collect in the coelomic fluid are removed by the nephridia by mechanisms similar to that of the urinary tubules of the kidney of the higher animals. This is because nephridia eliminate excretory matter both from the blood as well as from the coelomic fluid. Water, ammonia and urea which constitute the principal nitrogenous wastes are removed from the coelomic fluid and blood by the process of filtration and diffusion. Contraction of the muscular walls of the excretory tube then force the fluid outside the body but some nephridia open into the gut to pass out the contents.

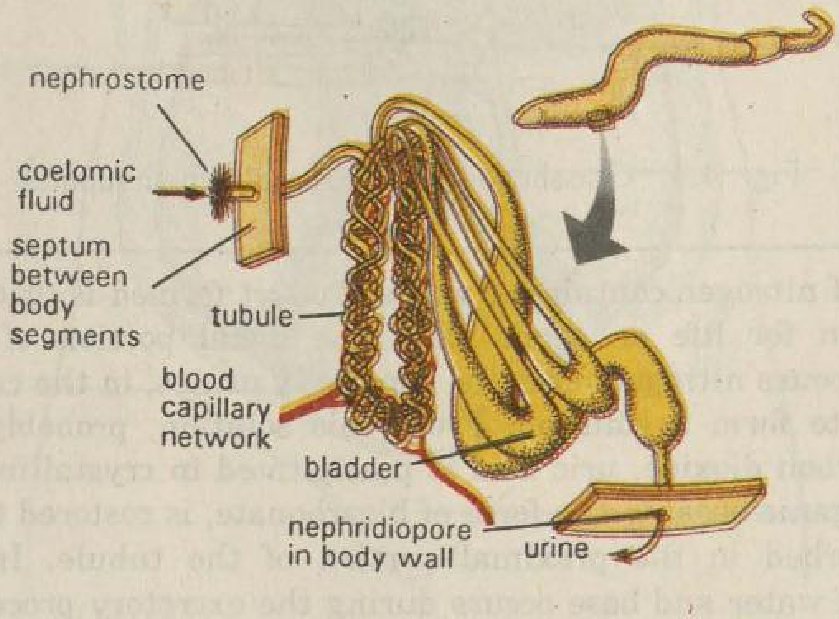


Fig 4.2. Nephridium of earthworm

Excretion in Grasshopper

Grasshopper and other insects remove their nitrogenous metabolic wastes by means of fine tubes known as Malpighian tubules. Each **Malpighian**

tubule is an outgrowth from the beginning of the proctodaeum and is lined by glandular cells. Their number varies but they are usually in groups, each group having 15 to 20 tubules. These tubes are blind at the distal end and bathe freely by the 'blood' in the haemocoel or body cavity while their proximal extremities open into the anterior portion of the hind gut. These excretory tubes extract waste products from the 'blood' and pass them into the hind-gut to be eliminated through the anus (Fig 4.3).

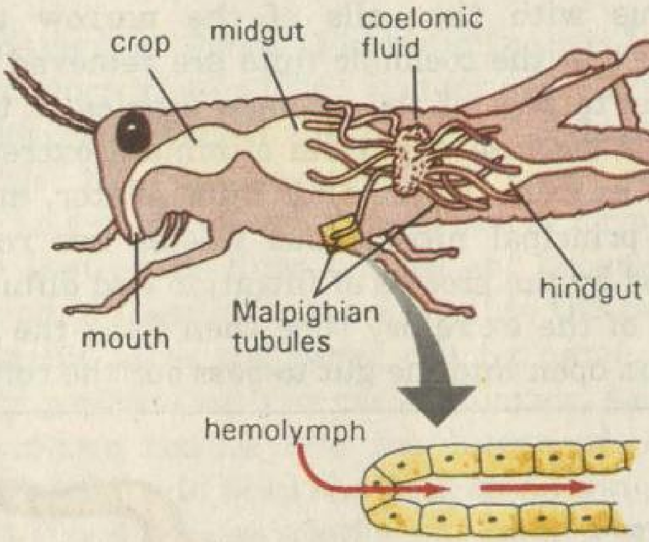


Fig 4.3. Grasshopper showing malpighian tubules.

The chief nitrogen-containing waste product formed is uric acid which is an adaptation for life on land. Since the distal portion of each tube is secretory, it pours nitrogenous salts, especially urates, in the cavity or lumen of the tube to form a solution. From this solution, probably through the agency of carbon dioxide, uric acid is precipitated in crystalline form. Water and the inorganic base, in the form of bicarbonate, is restored to the blood by being reabsorbed in the proximal portion of the tubule. In this way, a circulation of water and base occurs during the excretory processes resulting in the elimination of uric acid but conserving the water and base.

Excretion in Man

In vertebrates, nitrogenous wastes are removed by the kidneys and other excretory structures associated with them. The two kidneys in humans are located against the dorsal abdominal wall,lateral to the vertebral column. The right kidney lies a little lower than the left one. The depression in the middle which is called the **hilus** is the site at which the main blood vessels, lymph vessels and nerves enter this organ and from where a tube known as **ureter** emerges. Each tube extends downwards and opens into the **urinary bladder.** The bladder opens to the outside through another tube known as **urethra** (Fig. 4.4).

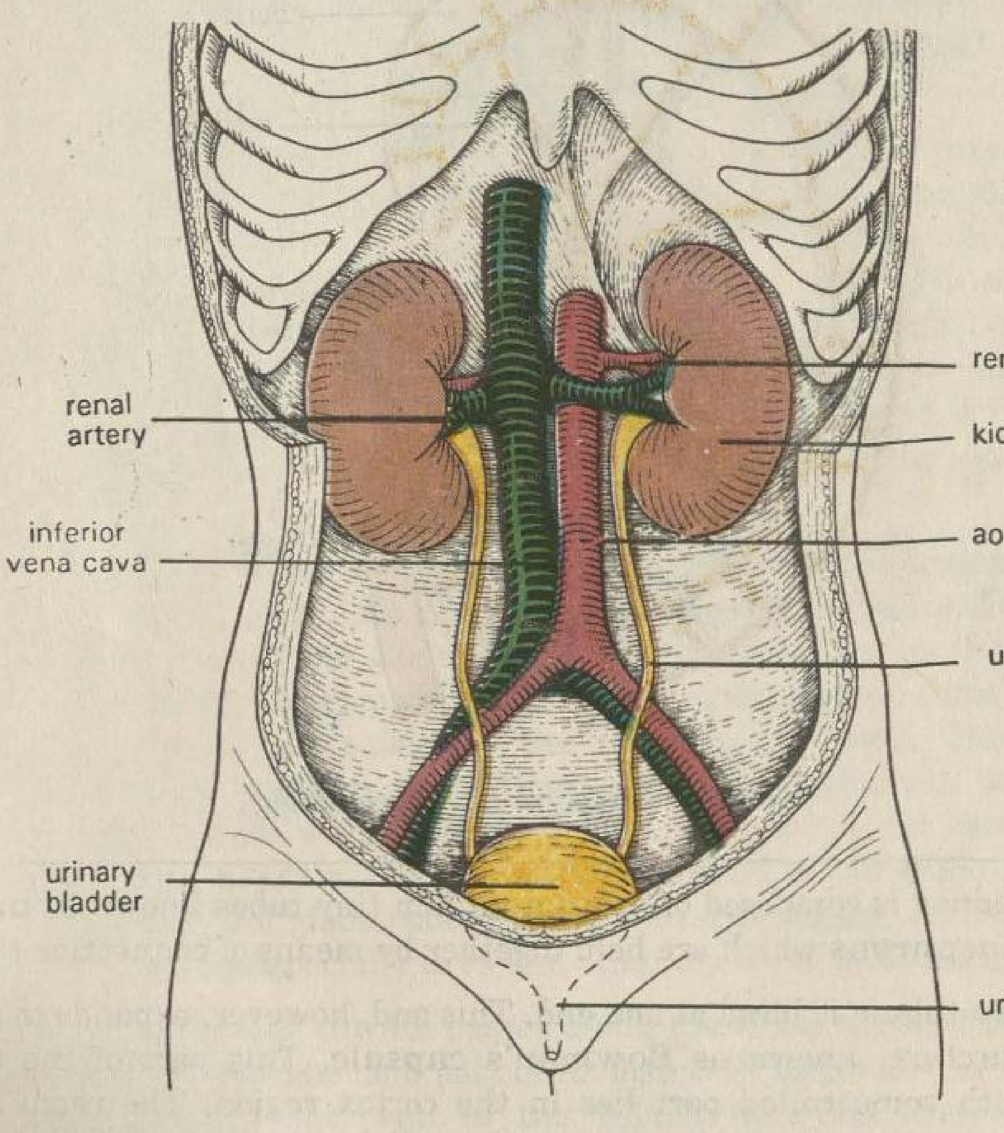

renal vein
renal artery
kidney
inferior vena cava
aorta
ureter
urinary bladder
urethra

Fig 4.4. Urinary system of man

In longitudinal section the kidney consists of two general regions, an outer darker region, the **cortex** and a considerably thicker inner region, the

medulla. The cavity in the central portion is known as **renal pelvis** which represents the enlarged proximal end of the ureter within the kidney (Fig. 4.5).

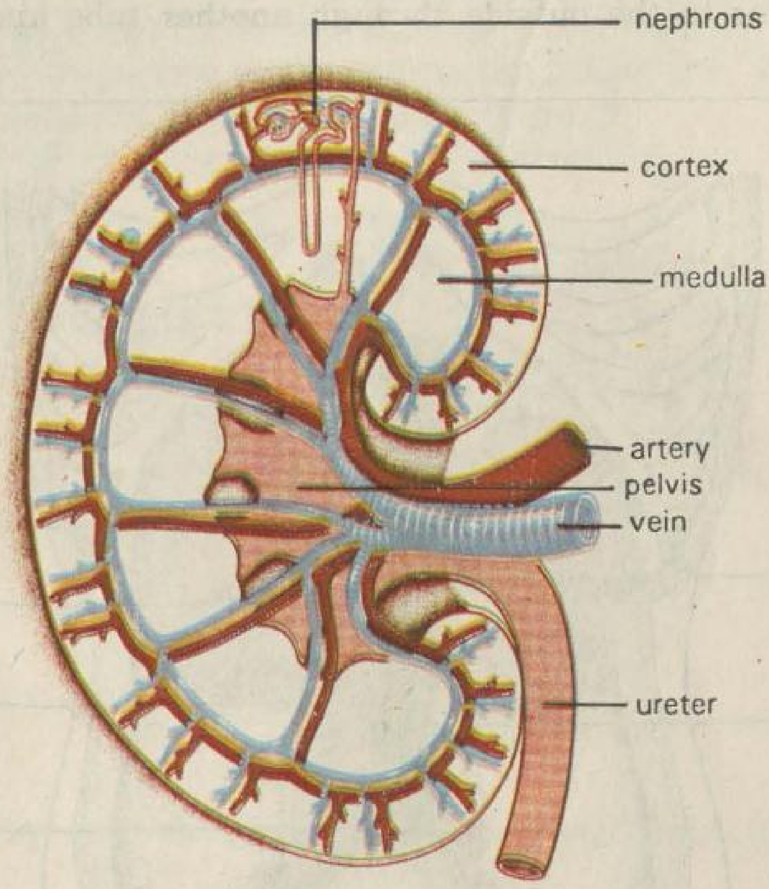


Fig 4.5. Structure of Human kidney.

Each kidney is composed of about a million tiny tubes known as **urinary tubules** or **nephrons** which are held together by means of connective tissue.

Each urinary tubule is blind at one end. This end, however, expands to form a cup-like sturcture, known as **Bowman's capsule.** This part of the tubule together with some coiled part lies in the cortex region. The renal artery divides into a great many arterioles and capillaries so that there is a very extensive system of blood capillaries, much of which lies in the cortex region. The concavity or cup-like portion of Bowman's capsule surrounds a thick cluster of capillaries called **glomerulus.** For some part the urinary tubule becomes quite convoluted and the next portion, called **Henle's Loop,** consists of a fairly straight portion which extends into the medulla region but loops back towards the cortex. The last portion of the tubule is again slightly convoluted and lies close to Bowman's capsule. It joins the last portions of several other nephrons to open into larger ducts called **collecting tubules** which finally open into the pelvis (Fig. 4.6).

Functioning of Kidney

The functioning of the kidney to form urine is the result of three processess that occur in each nephron: (1) pressure filtration through the glomerulus; (2) reabsorption of the filtrate as it passes through the various portions of the tubule; and (3) tubular secretion.

Urea constitutes 60 to 90 percent of all the nitrogenous materials in the urine of man and it is formed principally in the liver from ammonia, certain amino group and carbon dioxide. As a matter of fact excess of amino-acids cannot be stored in the body. Instead, these may be converted to carbohydrates (glycogen) by the removal, from the molecule, of the amino group ($-NH_2$). There is a very complex cyclic sequence of enzymatic reactions called the **urea cycle** as a result of which urea is formed from ammonia, carbon dioxide and NH_2 group. This enters the blood stream and is carried to the kidneys.

The first step in the formation of urine involves the separation of fluid from the blood by a simple mechanical process of pressure filtration. The tortuous capillaries of the glomerulus offer resistance to the flow of blood so that a high pressure is set up. This pressure causes fluid to filter out through the capillary walls and collect in the Bowman's capsule. This glomerular filtrate normally contains only those dissolved materials to which the capillary and tubule walls are permeable. So, except for the blood cells, plasma proteins and fats, the composition of fluid is the same as the blood. This means that the glomerular filtrate contains sugars, amino-acids, salts, nitrogenous wastes especially urea and other dissolved substances.

As the glomerular filtrate passes along the renal tubule from Bowman's capsule, most of its water and part of its dissolved materials are continuously reabsorbed through the wall of the tubule into the surrounding blood capillaries. The reabsorption process is highly selective because much of the water, glucose and many other dissolved materials are returned to the blood stream while urea and other products of protein metabolism are absorbed to a very little extent. This selective reabsorption prevents the loss of useful substances from the blood stream. Thus in the first part of the urinary tubule, at its convoluted region, nearly 85 percent of the water, sodium ions, chloride ions, most of the bicarbonates and all the glucose of the glomerular filtrate are absorbed back into the blood stream. Then along the Henle's loop and the latter convoluted part of the tubule, there is further selective reabsorption so that the remaining liquid in the tubule which may now be called urine contains only the waste products such as urea, inactive hormones, excess salts and water.

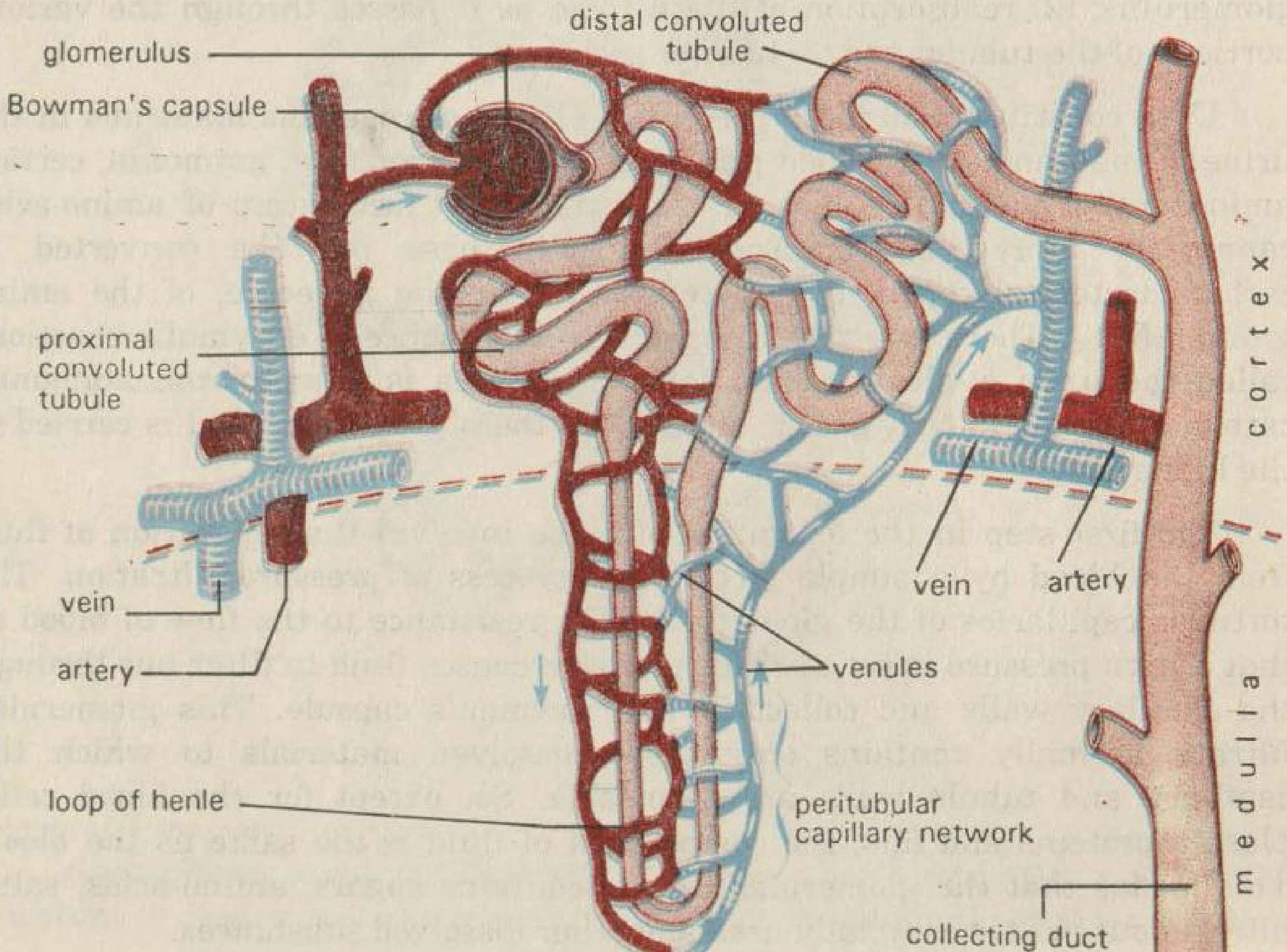

distal convoluted tubule
glomerulus
Bowman's capsule
proximal convoluted tubule
cortex
vein
artery
vein
artery
venules
loop of henle
peritubular capillary network
medulla
collecting duct

Fig 4.6. Human kidney showing the arrangement of urinary tubules

The active transport mechanism in selective reabsorption is energy-requiring so a third process also helps in urine formation whereby several substances are transported from the blood by the tubule cells into the filtrate and that process is known as **tubular secretion**. This process by contributing to the excretory function of the nephron, increases the overall efficiency in extracting waste products from the blood. But it must be noticed that in glomerular filtration glomeruli play a passive role since the energy of filtration is supplied by the heart via the pressure of blood. The urine then passes down the collecting tubule and from there enters the pelvis of the kidney where it continues down the ureter to the bladder. The sphincter muscles at the base of the bladder hold the urine. At intervals the urine is passed out. In babies, the sphincter muscle is controlled by a reflex action so that when the bladder is full it is emptied almost involuntarily. After about two years or so, the muscles can be controlled voluntarily.

Composition of Urine

There is a remarkable variation in the volume and composition of urine which shows that the kidneys are able to regulate the volume and composition of the blood and other tissue fluids. The pH of urine may vary from 4.6 to 8.00 and its yellowish colour is due to several pigments especially the haemoglobin and bile breakdown in the liver. Urine ordinarily consists of 95 percent water and 5 percent dissolved solids out of which urea constitutes about 2 percent, uric acid and ammonium compounds 1 percent. The rest of the 2 percent is made by other organic and inorganic salts.

Hormonal Effects on Kidney's Function

The proximal or first part of the urinary tubule which is convoluted and responsible for the reabsorption of most of the glucose is under the control of insulin which is a hormone of the pancreas. If glucose is present in the urine, the most common reason for this is the insufficiency of insulin as a result of which there is incomplete carbohydrate metabolism and there is high concentration of sugar in the blood and therefore, in the glomerular filtrate. This excessive glucose cannot be reabsorbed efficiently and therefore begins to pass out with the urine, a disease known as **diabetes mellitus**. The distal convoluted portion of the urinary tubule and perhaps the Henle's loop is mainly under the control of antidiuretic hormone secreted by the posterior pituitary gland and it promotes the reabsorption of water by altering the permeability of the membranes. A decreased water supply to the body results in increased secretion of the hormone which decreases the volume of urine formed. On the other hand, increased water intake by the body leads to a decreased secretion of the hormone and more water can be lost by urine. So it is a self regulatory mechanism for maintaining the water balance of the body.

Problems of Heat Production and Regulation of Body Temperature

In addition to the chemical waste materials, heat is also constantly formed due to metabolic processes and may also be considered as a waste product. Animals must get rid of the excessive heat, although body also constantly loses heat from its surface to the atmosphere, mainly by convection and radiation. Evaporation of water from the surface of the skin also removes heat from the body. Normally a balance is maintained so that the rate of heat loss and gain are the same, as for example, the human body temperature is maintained at about 36.8°C or 98.6°F. This means that body should not be allowed to be over-heated or over-cooled and there are mechanisms to regulate it.

Over-heating may be caused by vigorous activity, disease, absorption of radiation from the sun and such external causes. If the blood reaching the brain is a fraction of a degree higher than normal, regulation of temperature must take palce and skin plays a vital role in this connection. More blood flows to the skin capillaries and some heat escapes into the air by radiation and convection. This phenomenon is called **vasodilation** and leads to the flushing of the skin because of the increased blood supply. At the same time sweat production takes place and the latent heat absorbed by the sweat leads to cooling on evaporation, thus reducing the body temperature. At the same time volume of urine is reduced to prevent dehydration.

If the body begins to lose more heat than it is generating, then blood supply to skin is reduced (vasoconstriction), sweat is not produced, internal metabolism, especially in the liver is accelerated and shivering may start so that muscular activity should generate more heat.

It should therefore, be noticed that homeostasis is a very complicated phenomenon involving the composition of body fluids, constitution of blood, and regulation of temperature. Several measures have to be taken for these. For example, liver has to control the glucose concentration, the lungs have to control the concentration of carbon dioxide, kidneys have to eliminate the harmful compounds such as urea as well as excess water and the skin has to regulate the blood temperature. All such activities may therefore be excretory as well as osmo-regulatory and keep a constant internal environment.

QUESTIONS

1. What general relationships exist between the environment in which an animal lives and its method of excreting nitrogenous wastes?
2. There are various types of excretory structures in the invertebrate animals. In what way are they basically alike or different? Do they contribute in homeostasis and how?
3. Name the various excretory organs in the vertebrates and the excretory products they excrete.
4. In what ways do the circulatory and respiratory systems play a part in excretion?
5. Explain the circumstances under which glucose passes out of the blood into the urinary tubules of the kidney yet it does not normally appear in the urine.
6. Explain why the elimination of water by the kidneys may be considered to be both excretion and osmoregulation.
7. Is there any relationship between blood composition and composition of urine? Why the two should be considered important in medical observation?
8. What is the role of heat production and heat control in an animal? Explain how constant temperature is maintained in a mammal?

COORDINATION IN ANIMALS

5

In multicellular animals there is growing tendency towards division of labour of the cells, better organization and complexity of structure and integration and regulation of activities as we proceed in the evolutionary process. As the cells become more and more specialized in the specific functions, they become more and more inter-dependent so that they have to work in cooperation with one another and there is a need to integra organize and control their activities. Integration means attainment of un out of diversity. It is more than merely summing up of processes because sometimes the result of integration becomes unpredictable. Organization means working together in a regular manner so that timing and relationship result in a smooth and effective activity and working together is not haphazard. Integration and organization could not be possible unless there was a central control. All these aspects such as organization, regulation, integration and control in the constitution and work of the complex multicellular animals come under the fold of the term **coordination**.

Let us take the example of breathing which seems rather simple. As you have studied earlier, lungs, nasal passage, diaphragm, intercostal muscles, ribs, blood vessels all play their part to receive oxygen and remove carbon dioxide. They surely work together in cooperation and interdependence but you know that so many other processes are associated with breathing, i.e., respiration and release of energy have to meet the demands of different situations. You are breathing at a normal rate now but when you are doing some hard job or exercise, there is a corresponding change in physiology. The rate and depth of breathing greatly increase during exercise, more oxygen is provided and more carbon dioxide is removed. The heart beats faster. There are still some more things connected with this process. For example, breathing is directly controlled so that carbon dioxide concentration in the blood tends to remain near a constant value and for this purpose there is a breathing centre in the brain which has to receive messages and send messages to regulate and control the breathing activity. So coordination is the remarkable ability to maintain a stability or constancy in the internal environment, known as **homeostasis** and it depends on a complex interplay of numerous dynamic processes ranging from the molecular to gross level for the sake of attainment of unity of the organism.

Coordination is brought about by the nervous system and the endocrine system. The former mainly consists of conducting tissue and the latter secretory tissue.

Nervous Coordination

There are three important components of nervous co-ordination; receptors, neurons and effectors, and the basic principle in this connection is the stimulus-response model. **Stimulus** may be defined as any quantitative or qualitative change in environment that can be detected by an organism usually through receptors. Reaction to the stimulus is known as **response.** As a matter of fact, responsiveness or irritability is a fundamental feature of living organism. The response, which is essentially similar in all organisms, consists of three successive steps: receipt of the stimulus by the receptors, conduction of the resultant signal in the form of impulse through the neurons, and reaction to the signal usually by the muscles or glands which may collectivley be called effectors.ö

Receptors may be the neurons themselves (their endings) or they may be cells or organs that are specialized for detecting stimuli. For example tactile cells of the skin which are sensitive to touch are separate cells while eyes and ears are very complex sense organs. **Neurons** or nerve cells are the unit of structure and function in the nervous system. They are specialized for transmitting nerve impulses.

Effectors are the structures that respond when they are stimulated by nerve impulses. In most animals, the principal effectors are the muscles and glands.

Nervous System of *Hydra*

The first well-defined nervous system among the animals is found in the coelenterates such as *Hydra*. It consists simply of a network of somewhat similar nerve cells ramifying through most of the organism. The nerve cells

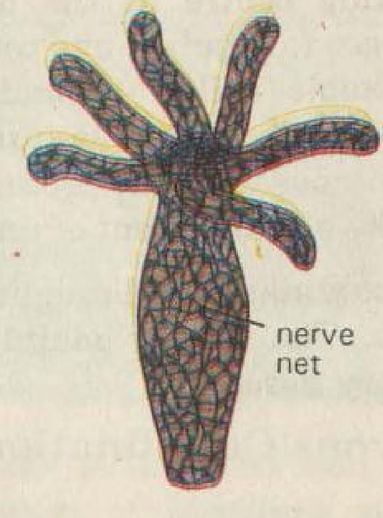


Fig 5.1.
Hydra showing the nerve net.

are inter-connected by means of synapse. Since there is no accumulation of neurons in the form of ganglia or 'brain', there is no central control in this animal. Nerve impulse conduction is slow and can occur in either direction depending on where the stimulus acts so the response is almost localized. Nevertheless, certain cells of the nervous system appear to be functionally different. Some of them are more sensitive to particular chemicals and mechanical changes in the environment and may be taken as receptors. Others transmit the impulses to different parts of the body while others repond to the impulses and may be regarded as effectors. *Hydra* has no specialized muscle cells but most of the cells of the inner and outer cell layers of the animal can contract. It is apparent that since the response is greatest near to the point of stimulation and gets progressively less in the more distant region, the nerve net offers some resistance to the passage of nerve impulses. The distance to which exitation is propagated through the nerve net depends, to a large extent, on the strength of the stimulus applied. This is because a stronger stimulus initiates a large number of nerve impulses so that more synapses are passed. For example, if *Hydra* is stimulated violently, it has the power of contracting very suddenly, a movement that is brought about by the simultaneous contraction of all the muscles present in the ectoderm and endoderm. The impulses are, in this case, conveyed with rapidity to all parts of the animal by special tracts of nerve cells for thorough conduction. In spite of all this *Hydra* is able to perform only limited movements. Tentacles are more contractile than the rest of the body but *Hydra* can bend and shorten its body (Fig. 5.1).

The Nervous System of A Planarian

The nervous system is greatly different from that of *Hydra*, for in addition to a superficial nerve net just below the epidermis, there is a deeper plexus embedded in the parenchyma. Moreover, there are the beginnings of a centralized nervous system and differentiation of the neurons. The nervous tissue is especially concentrated into a bilobed mass called **cerebral ganglia** or **'brain'** in the anterior region of the body from where a pair of longitudinal tracts or nerves extend in the body. The nerve cells in these longitudinal nerve cords serve as link between stimulus and response. The ganglia act as a co-ordinating centre for the various nerve impulses but it should not yet be regarded as brain. Because of a comparatively better developed nervous system, flatworm shows a more varied behaviour and more rapid responses. Moreover, the anterior region is also provided with sense organs in the form of eyes and chemo-receptors. If the cerebral ganglia are removed, locomotion, feeding and breeding is upset but the action of the cilia of the body wall is not disturbed which seems to be controlled by the superficial nerve net. The receptor cells are sensitive to light, pressure, touch and chemical stimuli. The central nervous system, which comprises of neurons, transfers impulses from the receptor cells to the motor neurons which lead to muscles (Fig. 5.2).

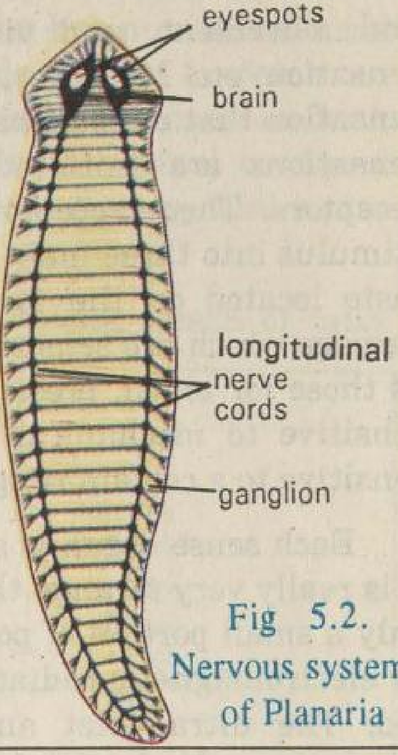


Fig 5.2. Nervous system of Planaria

The Nervous System of Man

Man, the most complex and advanced of the multicellular animals shows the same basic plan of nervous system as other animals in the form of receptors, neurons, brain and spinal cord, nerves and effectors. But the brain of man is a unique structure which has enabled him to convey intricate thoughts to other members of his species in the form of language, to develop and manipulate tools and to transmit knowledge to the next generations. Basically, the nervous system is the principal means of communication between the body parts; it serves to integrate their varied activities of the body. It performs this highly specialized function by receiving various stimuli to which it responds by transmitting messages or impulses to different tissues and organs. Its functioning results in adjustments which are more favourable for survival.

Receptors in Man

Information about the external world and internal environment is received by means of receptors or sense organs. The commonly described "five senses" in the form of touch, smell, taste, hearing and sight in fact represent an incomplete list of the senses. We now recognise at least 11 distinct sensations or senses in man, i.e., in addition to the five mentioned above there are senses for warmth, cold, equilibrium, pain, awareness of position and movement, and visceral sensation such as hunger, nausea, sexual sensation, etc. Moreover, extra-sensory perception in man is a unique kind of sensation that enables him to predict, foresee or imagine things. The various sensations are initiated by stimulations of various specialized sensory receptors. These receptors can be grouped according to the nature of the stimulus into three main subdivisions: (1) chemical receptors such as those for taste located on the tongue and for smell located in the nose and nasal passage which are sensitive to chemical stimuli; (2) mechanical receptors such as those for touch, pressure, pain, temperature, sound and motion, which are sensitive to mechanical stimuli; and (3) photoreceptors or eyes which are sensitive to a certain range of wavelengths constituting the visible light.

Each sense organ is specialized to receive a specific type of stimulus. But it is really very strange that even in man any one type of sense organ receives only a small portion of possible stimuli. For example, our eyes are stimulated by electromagnetic radiations between the short-wave violet to the long-wave red. The ultra-violet and infra-red do not stimulate our eyes but their presence can be detected by special instruments. Similarly, our ear can detect sounds ranging in frequency from about 20 to 20000 cycles per second. It is most sensitive to sounds between 1000 and 2000 cycles per second. On the other hand, the range of frequency of sound waves used by bats is from about 30,000 to 70,000 vibrations per second and, therefore, beyond the limit of human hearing.

Neurons

The neurons or nerve cells are the structural and functional unit of the nervous system. Each neuron consists of the cell body containing the usual parts such as the nucleus, cytoplasm, and inclusions but the difference from other kinds of cells of the body is due to their cytoplasmic extensions called **processes** or **fibres**. There is some disagreement about the terminology applied to these processes or fibres. If we accept the principle of naming the processes according to the conduction of impulses then one or more branching processes may be called **dendrites**, that conduct impulses towards the cell body while a single long fibre, called an **axon**, conducts impulses away. There are three main types of neurons: **sensory**, **motor** and **associative**. In the sensory neuron, the single, elongated dendrite is called a dendron because it carries impulses to the cell body while the shorter process is axon becasuse it conducts impulses away. Both these processes arise from near the cell body. In the motor neuron, there is a long axon and a number of small processes given out from the cell body are the dendrites. As the name show, sensory neurons conduct impulses from the receptors to the central nervous system while motor neurons carry them from the central nervous system to the effectors. The cell body of these cells usually lies in the brain or spinal cord while the axon or dendron extends for a considerable length to reach an organ. The associative neurons have many short branching processes on both sides of the cell body. These cells occur exclusively in the spinal cord and brain and serve as intermediate links between numerous sensory and motor neurons (Fig. 5.3).

In some cases the fibre is surrounded by an insulating steath of fatty

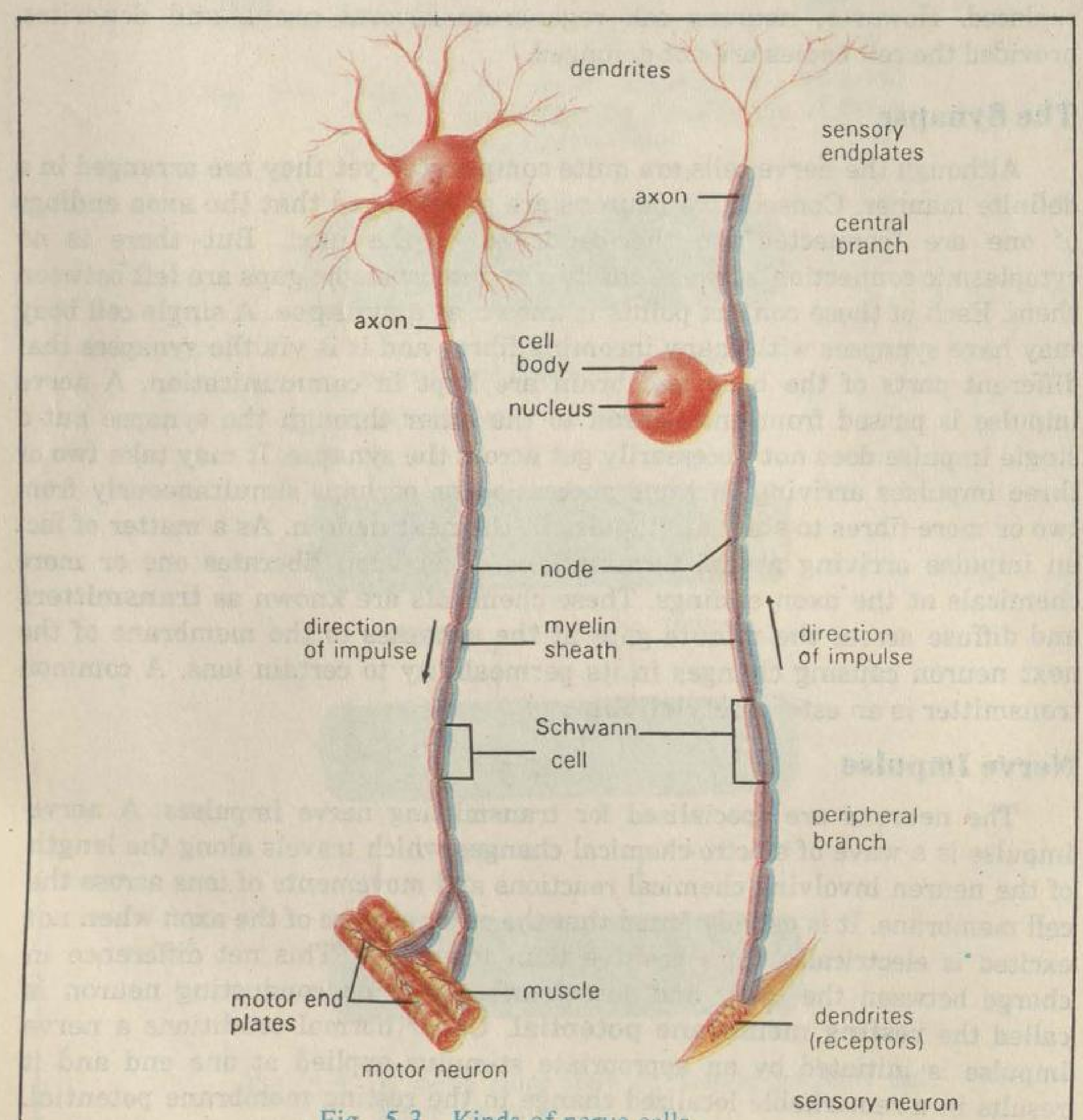

dendrites
sensory
endplates
axon
central
branch
axon
cell
body
nucleus
node
direction
of impulse
myelin
sheath
direction
of impulse
Schwann
cell
peripheral
branch
motor end
plates
muscle
dendrites
(receptors)
motor neuron
sensory neuron

Fig 5.3. Kinds of nerve cells

material called the **myelin sheath** which may again be surrounded by a thin membrane and both of these are interrupted at regular intervals by **constrictions or nodes.** The sheath prevents the indiscriminate distribution of the nerve impulse to adjacent nerve fibres and serves as a means of enhancing the rate of conduction of nerve impulse.

There are approximately ten to twelve billion nerve cells in the human nervous system. Unlike other body cells, neurons lack the ability to divide to form new cells. Once a neuron or its cell body is destroyed it cannot be replaced. However, neurons can regenerate several axons and dendrites, provided the cell bodies are not damaged.

The Synapse

Although the nerve cells are quite complicated yet they are arranged in a definite manner. Consecutive neurons are so arranged that the axon endings of one are "connected" to the dendrites of the next. But there is no cytoplasmic connection between the two and microscopic gaps are left between them. Each of these contact points is known as a **synapse.** A single cell body may have synapses with many incoming fibres and it is via the synapses that different parts of the body and brain are kept in communication. A nerve impulse is passed from one neuron to the other through the synapse but a single impulse does not necessarily get across the synapse. It may take two or three impulses arriving in rapid succession or perhaps simultaneously from two or more fibres to start an impulse in the next neuron. As a matter of fact an impulse arriving at the terminations of an axon liberates one or more chemicals at the axon endings. These chemicals are known as **transmitters** and diffuse across the minute gaps at the synapses to the membrane of the next neuron causing changes in its permeability to certain ions. A common transmitter is an ester **acetylcholine.**

Nerve Impulse

The neurons are specialized for transmitting nerve impulses. A nerve impulse is a wave of electro-chemical changes which travels along the length of the neuron involving chemical reactions and movements of ions across the cell membrane. It is usually found that the outer surface of the axon when not excited is electrically more positive than the inside. This net difference in charge between the inner and outer surface of a nonconducting neuron is called the **resting membrane potential.** Under normal conditions a nerve impulse is initiated by an appropriate stimulus applied at one end and it results in a remarkable localized change in the resting membrane potential.

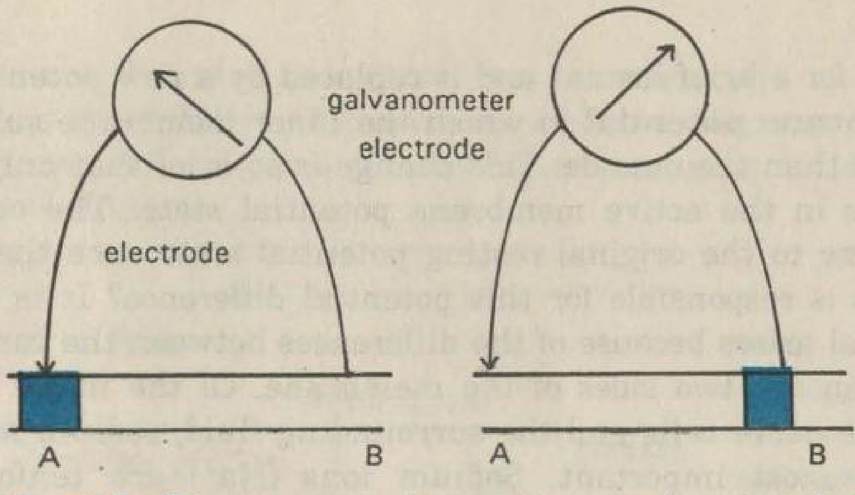

galvanometer
electrode
electrode
A
B
A
B

Fig 5.4. Diagram to show changes in electrical potential accompanying the passage of nerve impulse along a nerve fibre.

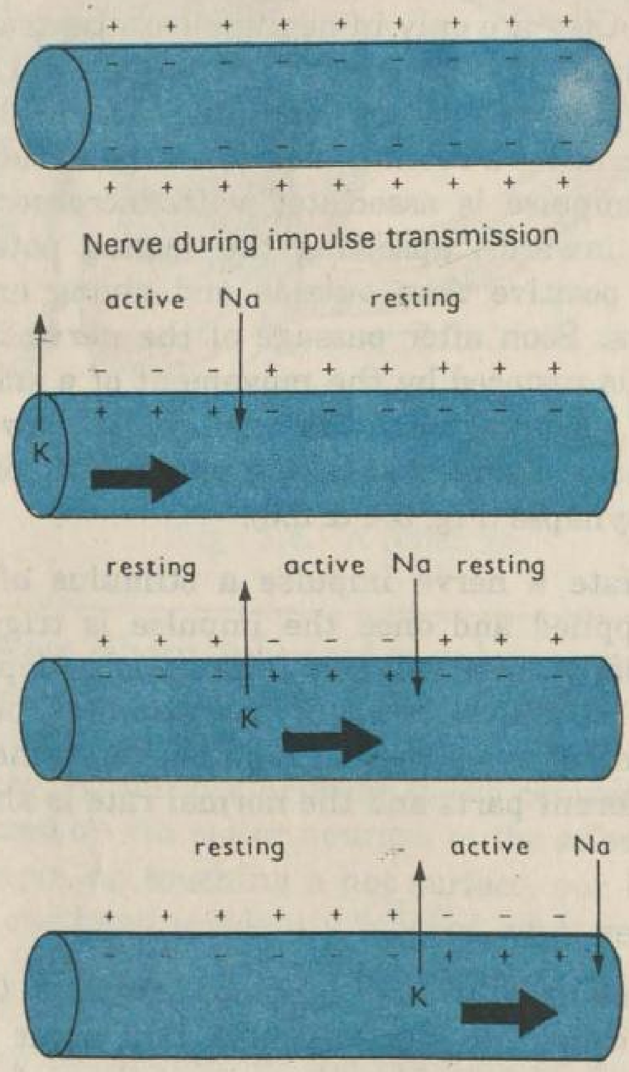

Nerve during impulse transmission
active
Na
resting
K
resting
active
Na
resting
K
resting
active
Na
K

Fig 5.5 A nerve fibre showing resting potential and active potential

It disappears for a brief instant and is replaced by a new potential called the **active membrane potential** in which the inner membrane surface becomes more positive than the outside. This change is so brief that only a portion of the neuron is in the active membrane potential state. The cell membrane quickly returns to the original resting potential state once the impulse has passed. What is responsible for this potential difference? It is believed that nerve potential arises because of the differences between the concentration of certain ions on the two sides of the membrane. Of the many kinds of ions present in the nerve cells and the surrounding fluid, sodium and potassium ions are the most important. Sodium ions (Na^+) are tenfold higher in concentration outside than inside the membrane surface,whereas potassium ions (K^+) are twenty times more concentrated inside than outside. Similarly the large negative organic ions are much more inside the neuron than outside the membrane,where they are only in negligible concentration. In the resting or non-conducting state, the nerve cell membrane permits only a small number of potassium ions,go outwards and thus leaving the negative organic ions behind and generating a resting membrane potential of 0.07 volts. The passage of a nerve impulse is associated with increase in permeability to sodium ions moving inwards, upsetting the resting potential momentarily making inside more positive than outside and giving an active membrane potential of 0.05 volts. Soon after passage of the nerve impulse the resting membrane,potential is restored by the movement of a small number of ions, especially potassium, moving out. The neuron is now ready to conduct another impulse. These changes go along the length of the fibre till the impulse reaches the synapse (Fig. 5.4 & 5.5).

In order to initiate a nerve impulse a stimulus of certain minimum intensity must be applied and once the impulse is triggered it cannot be stopped. As to how many fibres will carry the impulse depends on the nature and intensity of the stimulus; stronger the stimulus, more fibres will be affected, but the speed of the stimulus remains the same. The speed of the impulse varies in different parts and the normal rate is about 100 meters per second.

Reflexes and Reflex Arc

Our body performs usually three kinds of activities: (1) **involuntary or automatic actions** which are the responses that occur automatically and without our awareness, such as heart-beat, secretions of the gastric glands, peristalsis, etc. (2) **voluntary actions** which are the responses by the will and may not be automatic or immediate, for example walking or running.

(3) **Reflexes** or **reflex actions** which are the responses to environmental changes, both internal and external and are immediate or automatic and without the intervention of will. These reflexes may be divided into simple and conditioned reflexes.

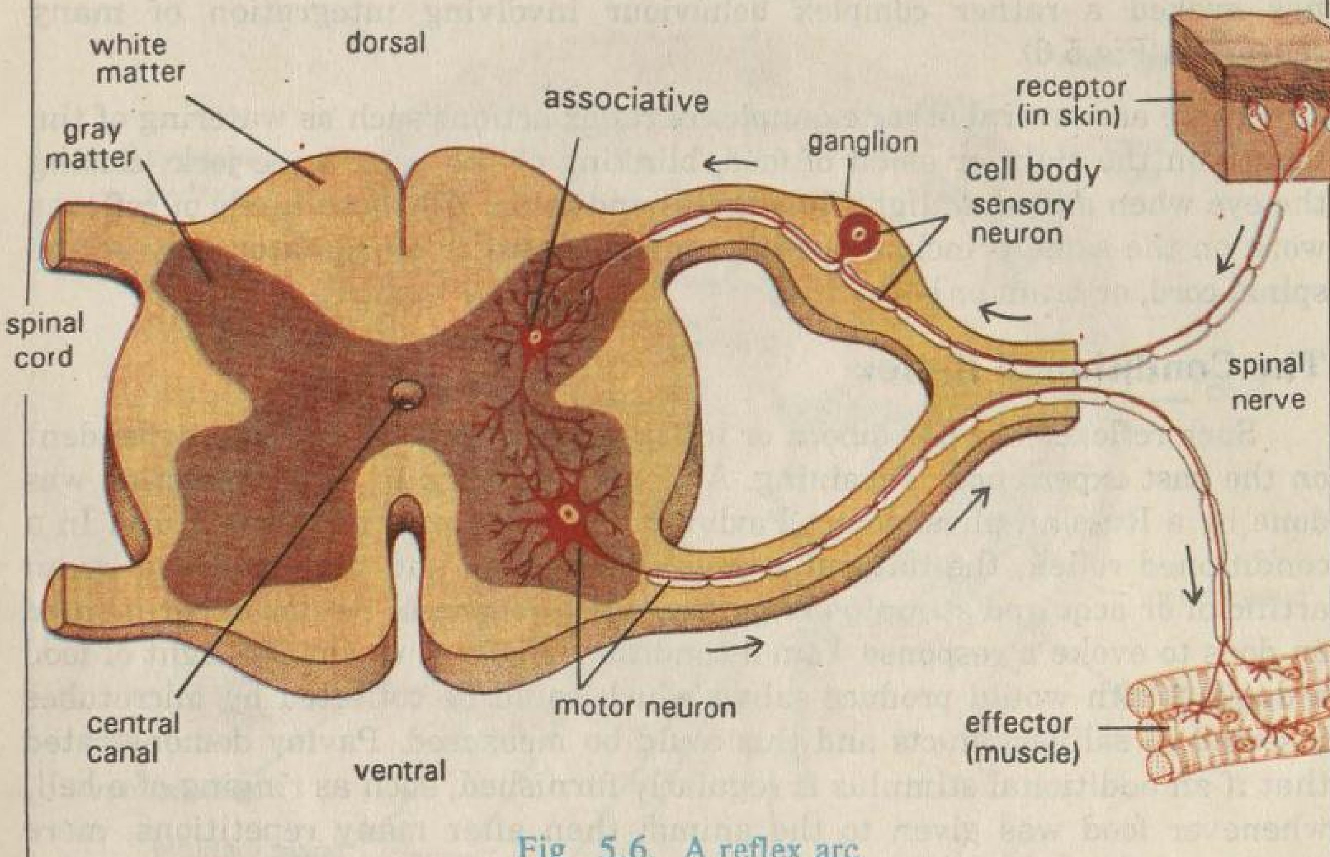

white matter
dorsal
gray matter
associative
ganglion
receptor (in skin)
cell body
sensory neuron
spinal cord
spinal nerve
central canal
ventral
motor neuron
effector (muscle)

Fig 5.6. A reflex arc

Simple reflexes are inborn, inherited or unlearnt responses to stimuli and are immediate and automatic. The structural and functional basis of the simple reflex is called the **reflex arc**. In this pathway, impulses are carried from the receptors to the sensory neurons to the central nervous system from where they are passed on via motor neurons to the effectors for the necessary response. For example, on touching a hot surface, our hand is automatically withdrawn. When our hand accidently touches a hot surface the receptors of the hand transmit impulses to the sensory neurons which carry them to the associative neurons of the spinal cord and the impulses are reflected to the motor neurons that carry them to the effectors or muscles of the hand to contract and the hand is at once withdrawn. But it must be noted that it is not a matter of a single isolated reflex arc and the response is not so simple as it seems to be. It must be pointed out that most reflex actions involve a number of reflex arcs rather than one and secondly there may be other responses such as feeling pain, expression of emotions such as fear or tension, bringing the hand to the face to look at and so on. This means that several muscles have shown responses and several mental processes have participated so what started as a simple stimulus in the form of a localized heat or burn has evoked a rather complex behaviour involving integration of many responses (Fig.5.6).

There are several other examples of reflex actions such as watering of the mouth on the sight or smell of food, blinking of the eyes, knee jerk, closing the eye when a flash of light falls across and so on. All these kinds of reflexes work on the same principle but the control centre or coordinator may be the spinal cord, or brain or both.

The Conditioned Reflex

Such reflexes are not inborn or inherited but are acquired and dependent on the past experience or training. A pioneering work in this connection was done by a Russian physiologist Pavlov in the early part of this century. In a conditioned reflex, the natural stimulus is tied up and then replaced by an artificial or acquired stimulus to get the same response. Pavlov experimented on dogs to evoke a response from a conditioned stimulus. On the sight of food a dog's mouth would produce saliva which could be collected by microtubes inserted in salivary ducts and this could be measured. Pavlov demonstrated that if an additional stimulus is regularly furnished, such as ringing of a bell, whenever food was given to the animal then after many repetitions, mere ringing of the bell (without even the sight of the food) would result in the secretion of saliva. So in this case, the natural stimulus (sight of food) was first tied up with artificial stimulus (ringing of bell) and in time the latter was enough to produce the same response (secretion of saliva). Training, learning by experience by eliminating inappropriate stimuli are the examples of conditioning. Both the simple reflexes and conditioned reflexes are important as automatic responses for protection and survival in our everyday life.

Central Nervous System (CNS)

The central nervous system consists of brain and spinal cord that perform a key function in the complex nervous activity. It can be compared to switchboard of the central telephone exchange for controlling, directing and integrating all messages but the central nervous system works at a much higher level than a switchboard. It can make judgments, inhibit, delay or make necessary alterations according to situations, while the switchboard mereley connects. Similarly, a computer or even a master computer cannot be compared to the CNS of humans because of the conscious and sub-conscious activities, emotions, and thinking. Such highly intricate processes are not possible within the range of a computer (Fig 5.7).

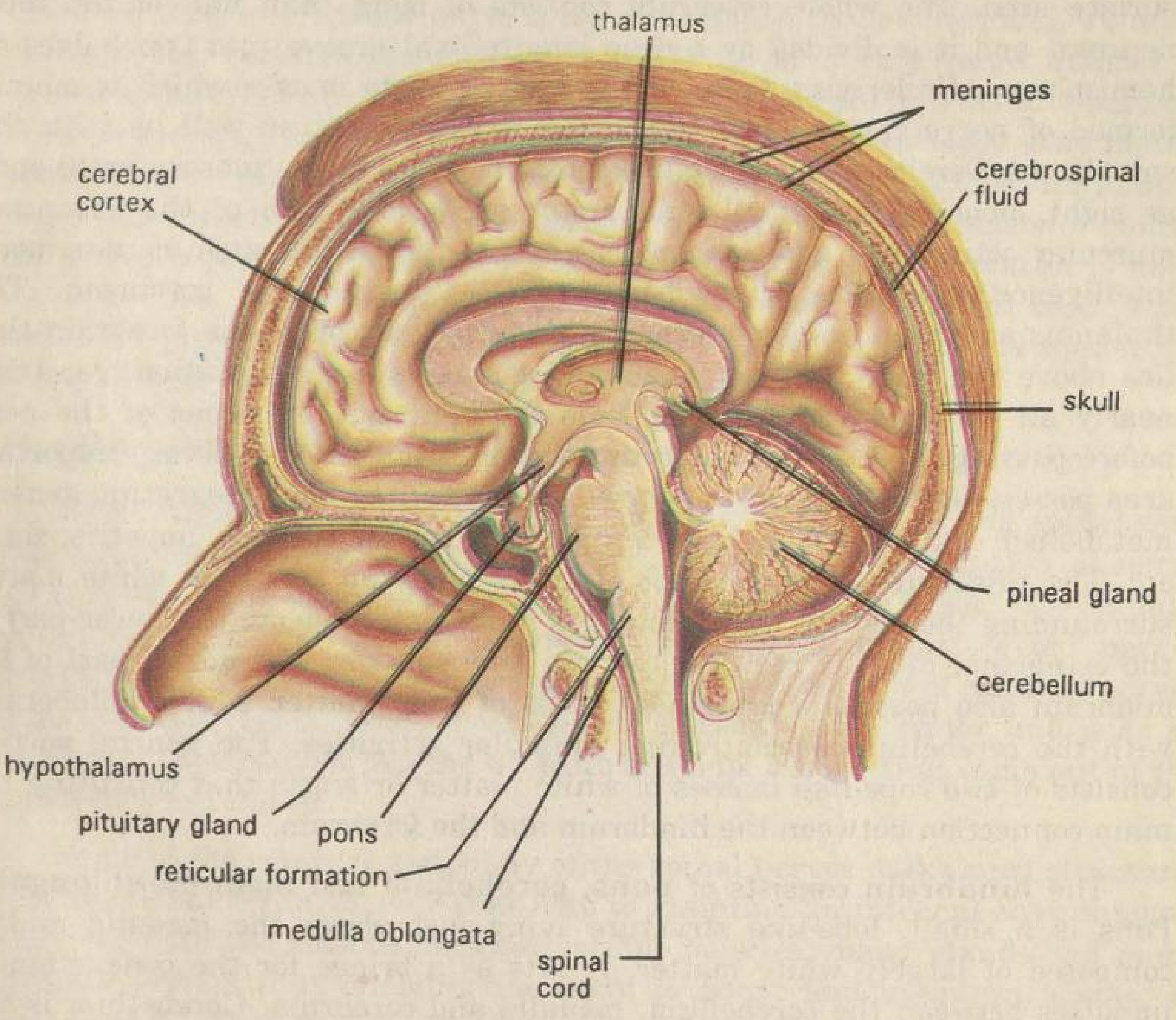

thalamus
meninges
cerebral cortex
cerebrospinal fluid
skull
pineal gland
cerebellum
hypothalamus
pituitary gland
pons
reticular formation
medulla oblongata
spinal cord

Fig 5.7. A section through the human brain.

Human central nervous system is made up of approximately ten to twelve billion neurons with their cell bodies lying within the brain and spinal cord while the long fibres of most of them come out to form nerves.

Conventionally speaking, the brain can be divided into three main parts: **forebrain, midbrain** and **hindbrain**. The **forebrain** consists of **cerebrum, thalamus** and **hypothalamus**. The cerebrum is the largest part of the human brain and represents the highest form of organization. Its surface, which is known as **cortex**, covers and overlaps most of the other brain areas. It is composed of gray matter of some two billion cell bodies forming a vast interconnecting mass arranged in folds or convolutions which increase its surface area. The whole cerebrum consists of more than half of the total neurons, and it is divided by a deep longitudinal groove into two halves or hemispheres. Underlying these, is the area of white matter which is mainly formed of nerve tracts which connect with the cortex as well as with the spinal cord. Cerebrum is the control centre of many of the sensory areas such as sight, hearing and smell, and motor areas for much of the voluntary muscular activity. In addition, many advanced functions such as memmory. intelligence, reasoning, judgement, etc. lie within the cerebrum. The thalamus and hypothalamus form the posterior portion of the forebrain that lies above the midbrain. The thalamus serves as a relay station, receiving nearly all the impulses arriving from different sensory areas of the body before passing them on the cerebrum. The hypothalamus is a very important area possessing visceral reflex centres for controlling and integrating general metabolism and regulating body temperature, water balance, appetite, sleep, etc. The **midbrain** is just a mass of tracts made up mostly of white matter surrounding the central cavity and lies immediately below the lower part of the cerebrum, midway between the two hemispheres. The dorsal part of the midbrain also possess a prominent mass of gray matter which collaborates with the cerebellum in controlling muscular activities. The ventral portion consists of two rope-like masses of white matter or tracts that constitute the main connection between the hindbrain and the forebrain.

The **hindbrain** consists of **pons, cerebellum** and **medulla oblongata**. Pons is a small, lobe-like structure lying just above the medulla and is composed of largely white matter. It acts as a bridge for the conduction of impulses between the cerebellum, medulla and cerebrum. Cerebellum is the second largest part of the brain but constitutes only about ten percent of the weight of the brain. It consists of two lateral hemispheres and a central narrow lobe, the vermis. Cerebellum also shows folds or convolutions and its interior is mainly made up of neuron cell bodies. This part controls and coordinates the balancing organs and the muscles, thus making precise and accurate movements possible. Removal of this part in animal does not cause actual paralysis but the movements are jerky and shaky, and poorly regulated. Recent evidence shows that cerebellum also integrates some sensory activities such as touch, sight and hearing.

The lowermost part of the brain forming the floor of the hindbrain is the medulla oblongata and it narrows down into the spinal cord. This region consists mostly of ascending and descending tracts of white matter with some gray matter in the interior. Medulla controls several reflex activities of involuntary nature such as heart beat, breathing, constriction and dilation of blood vessels, etc. **Spinal cord** is an oval-shaped, hollow cylinder, running through the vertebral column. It is made up of a very large number of neurons, the cell-bodies and fibres of which are arranged in a definite pattern. In cross-section, the spinal cord shows an inner butterfly-shaped gray matter containing a central canal, and the outer portion composed of white matter. As in other parts of the nervous system, the gray matter consists of neuron cell bodies and non-myelinated parts of the fibres. The white matter is made up of bundles of myelinated nerve fibres or tracts. The spinal cord is the centre for great many reflexes and it serves as a pathway for the conduction of impulses to and from different parts of the body and brain.

The Peripheral Nervous System

Generally speaking, the nerves arising out of the brain and spinal cord constitute the peripheral nervous system. A nerve is a collection of nerve fibres dendrites or axons bound together with connective tissue. Nerves may be sensory, motor or mixed depending on their functions. Mixed nerves possess the processes of both types of neurons. Twelve pairs of cerebral nerves arise from the brain some of which are sensory, some motor and a small number of them mixed. All the 31 pairs of spinal nerves that come out of the spinal cord are mixed.

Some of the cerebral and many of the spinal nerves make such structural and functional arrangements that help to maintain an internal environment. They regulate the smooth muscles, cardiac muscles, many glands and many internal organs thus enabling the body to adapt and maintain a state of equilibrium. This part of the peripheral nervous system constitutes the **visceral** or **autonomic** system.

Conscious and Unconscious Activity

We perform so many activities about which we are aware of and perform them consciously. A lot of voluntary action belong to this category. But there are so many other activities that are controlled by the brain without our conscious participation. For example, during exercise many physiological changes are involved that are carried out unconsciously. There is an increase in the consumption of glucose and oxygen, and more carbon dioxide is produced. The requirements are met by increasing the rate and depth of breathing and accelerating the movement of blood which are brought about by the chemicals at the nerve endings on the heart and so on. All these changes occur without our conscious effort or thinking. Such unconscious activity is not totally understood but autonomic nervous system plays an important role in this. Recent studies of brain functions suggest that emotions, moods and behaviour may be significantly influenced by certain compounds normally found in the brain and effects of drugs have also been studied that disturb the conscious and unconscious activity.

Chemical Coordination
The Endocrine System

Previously it was thought that nervous coordination was quite different from the chemical coordination, but recent studies on the chemicals produced at the nerve endings acting as transmitters, inhibitor or accelerators broke down the distinction between nervous and endocrine coordination as separate systems. It is now much more obvious that nervous sytem and endocrine system work in similar or identical ways in controlling body functions. But it must be noticed that nerve impulse travels much faster and hormones circulate less rapidly in the blood so as to reach the site of action. Moreover, sometimes, the effect of hormone may be more generalized and that of the nerve impulse more specific. Hormones may also control some long-term changes such as rate of growth, rate of activity and sexual maturity.

Endocrine system consists of some ten endocrine glands lying in different parts of the body (Fig 5.8). These glands produce chemicals known as **hormones** which enter the blood stream to be carried to the site of action because these glands do not have any duct to carry the chemicals. These chemicals or hormones are organic substances of varying structural complexity. Many of them are proteins or polypeptides and some, such as the sex hormones, are steroids. They may either stimulate or inhibit a function but generally do not initiate a process. For example, sugars may be metabolized in absence of the hormone insulin but the rate will be definitely slower. So they are the chemical messengers which regulate and control a number of activities of the body.

The **Thyroid gland** lies in the middle portion of the neck, slightly below the larynx and consists of two lateral lobes. This gland has the remarkable ability to store and accumulate iodine which is a constituent of the thyroid hormones collectively called **iodothyroxines**. These hormones stimulate the

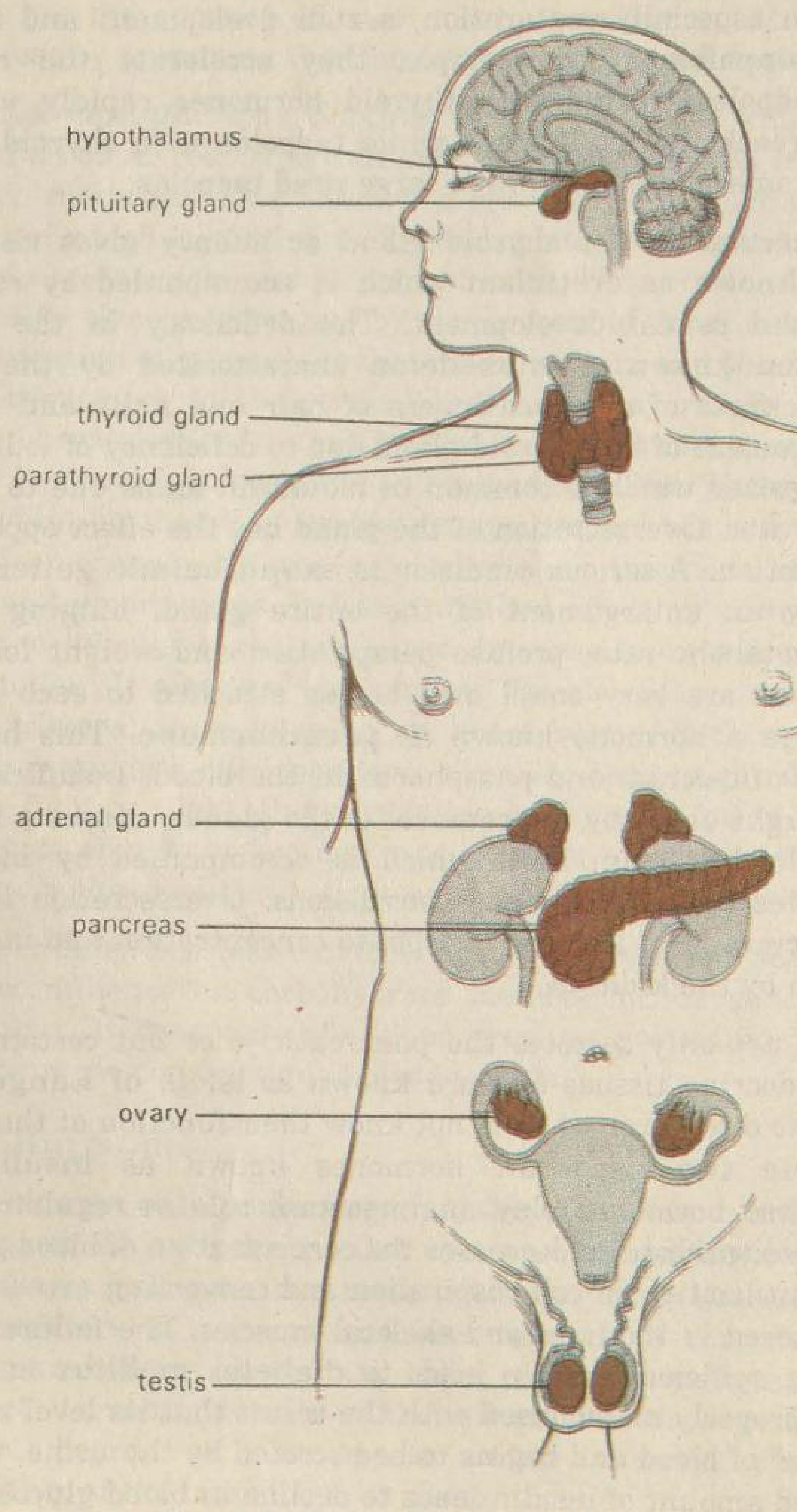

hypothalamus
pituitary gland
thyroid gland
parathyroid gland
adrenal gland
pancreas
ovary
testis

Fig 5.8. Various endocrine glands in humans.

rate of oxygen consumption or oxidative metabolism which resulting in heat production in various cells and tissues of the body. They also regulate the processes of growth especially maturation, sexual dvelopment and mental development. In amphibians for example, they accelerate the rate of metamorphosis. Tadpoles treated with thyroid hormones rapidly undergo metamorphosis to reach the adult stage while tadpoles with thyroid tissue removed do not metamorphose but grow to large sized tadpoles.

Insufficient secretion by the thyroid gland at infancy gives rise to a dwarfed condition known as **cretinism** which is accompanied by retarted physical, mental and sexual development. The deficiency in the adults produces a condition known as **myxedema** characterized by the lower metabolic rate, thickness of skin brittleness of hair and nails and mental lethargy. An enlargement of the thyroid gland due to deficiency of iodine is a disease known as **goiter** which is common in mountain areas due to lack of iodine in soil and water. Oversecretion of the gland has the effect opposite to those for undersecretion. A serious condition is **exophthalmic goiter** which is characterised by an enlargement of the entire gland, bulging of the eyeballs, higher metabolic rate, profuse perspiration and weight loss. The **Parathyroid glands** are very small oval bodies attached to each thyroid gland. These secrete a hormone known as **parathormone.** This hormone regulates the level of calcium and phosphorus in the blood. Insufficiency of parathormone, brought about by the removal of the glands, causes a marked decrease in the blood calcium level which is accompanied by increased excitability in nerves and muscles and convulsions. Oversecretion leads to increased blood calcium level lowered phosphate concentration and increased excretion of calcium by the kidneys.

The **Pancreas** not only secretes the pancreatic juice but certain areas within it act as endocrine tissues and are known as **islets of Langerhans** after the name of the discoveror who did not know their function at that time. These islets secrete two important hormones known as **insulin** and **glucagon.** Both these hormones play an important role in regulating the carbohydrate metabolism. Insulin decreases the concentration of blood glucose by accelerating its utilization in cell respiration and converting excess sugar to glycogen to be stored in the liver and skeletal muscles. The failure of the pancreas to produce sufficient insulin leads to **diabetes mellitus** in which case glucose is not properly metabolised with the result that its level rises to above 60 mg/100 cm^3 of blood and begins to be excreted by the urine. On the other hand increased amount of insulin leads to decline in blood glucose level and accelerated conversion of glucose to glycogen in liver and muscles, therefore, persons suffering from diabetes need regular injections of insulin. Glucagon has the opposite effect of insulin, tending to increase the level of blood glucose by promoting the change of liver glycogen to glucose.

The **Adrenal glands** are located on the top of the kidneys. Each gland consists of an outer reddish-brown part, the **cortex** and an inner grayish part known as **medulla**. The adrenal cortex secretes several hormones, an important of which is **cortisone**. These hormones influence the carbohydrate and protein metabolism and balance of salts. They accelerate the conversion of proteins to glucose (glycogen) by the process of deamination and regulate the concentration of mineral ions especially sodium and potassium in the body fluids. Disturbances in the cortical hormones may result in inflammation, allergy and breakdown of connective tissue. The adrenal medulla secretes two important hormones, **adrenaline** and **noradrenaline**. These hormones play a part in regulating the blood circulation and prepare the body for situations of stress and emergency. Of the two, adrenaline functions effectively during emotions and emergencies. It has a marked effect on enhancing enzymatic conversion of liver glycogen to glucose, increase in oxygen consumption and heat production. It also tends to increase the blood flow in skeletal muscles, heart and viscera, thus stepping up heart beat. All these changes would increase the animal's efficiency in a situation that might demand vigorous activity for fight or flight. But adrenaline is also secreted in many situations which promote anxiety or fear and produce other sensations such as thumping of the heart, hollow feelings in the stomach and paling of face, etc.

Noradrenaline has less extreme effects. It does not seem to have any appreciable influence on carbohydrate metabolism, oxygen consumption or cardiac output. It does raise the blood pressure but unlike adrenaline it is responsible for the constriction of blood vessels.

Male Sex Hormones

The testes not only produce sperms, they also secrete male sex hormones usually known as **androgens**. Out of these **testosterone** is the principal hormone. These hormones are responsible for the appearance of secondary sexual characters at puberty and maintenance of reproductive functions including sexual desire. Testes removal or castration in the human male prior to the onset of puberty results in the failure of secondary sexual characters (moustache, beard, etc) to appear. After puberty, castration causes malfunctioning of the reproductive system.

Female Sex Hormones

Ovaries not only produce ova, but also secrete a number of hormones known as **estrogens**. Since the female has to undergo several physiological changes from the time of puberty, there are several hormones produced according to the definite periods or stages. In general, these hormones control the development of secondary sexual characters (mammary glands etc.), cause the lining of the uterus to thicken just before an ovum is released; the process of ovulation and conception and maintenance of pregnancy; **Progesterone** is an important hormone in this connection. It is secreted during the latter half of the menstrual cycle chiefly by the temporary endocrine tissue, the **corpus luteum** which rapidly develops in the ruptured follicle shortly after the release of the egg. This hormone promotes the further thickening and vascularization of the uterus to prepare it to receive the developing embryo. If fertilization has occured, this hormone maintains pregnancy and prevents the uterus from contracting until the onset of 'labour' prior to birth.

Pituitary

The pituitary gland or hypophysis is a very small gland, about the size of a large pea but it is the most important of all the glands. It is located at the base of the brain over the roof of the mouth and attached to hypothalmus by a short stalk. It is divided into two lobes the upper or anterior lobe and lower or posterior lobe. Both these parts release several hormones some of which regulate the organ systems of the body while others act upon and regulate the activity of other endocrine glands. Due to this, pituitary is considered as a 'master gland'. The anterior lobe of the pituitary mainly affects, regulates and maintains the development and function of other endocrine glands. There are at least six hormones produced by this part which are listed as under.

1. **Thyroid-stimulating hormone** (TSH) controls development and maintenance of thyroid gland including the conversion of iodine into the thyroid hormones.
2. **Adrenocortiotrophic hormone** (ACTH) stimulates the activity of the cortex of the adrenal gland.
3. **Growth hormones or Somatotropic hormones** (STH) stimulates growth especially in terms of body weight and skeleton and in case of oversecretion leads to gigantism while undersecretion leads to dwarfism.

4. **Follicle-stimulating hormone** (FSH) stimulates the growth of Graafian follicle of the mammalian ovary. In the male, starting at puberty FSH induces spermatogenesis in the seminiferous tubules of the testis.
5. **Luteinizing hormone** (LH) stimulates the development of egg as well as its release from the Graafian follicle. It also stimulates the formation of corpus luteum which is responsible for the production of progesterone.
6. **Lactogenic hormone** (LTH) stimulates the production of mammary glands together with the estrogens but in case of conception it is responsible for the production of milk for nursing the baby after birth.

Posterior pituitary lobe works in close collaboration with the hypothalamus and is responsible for the secretion of two important hormones:

(i) **Oxytocin** causes a powerful contraction of uterus during and after birth and also causes the ejection of milk when mammary glands are stimulated by suckling.

(ii) **Vasopressing or Antidiuretic hormone** (ADH) has striking influence in decreasing the amount of water to be lost from the body by way of urine by increasing its reabsorption and sodium ions from the uriniferous tubules. Its undersecretion results in the disease **diabetes insipidus** in which huge volumes of urine are excreted daily.

Interaction and Feedback Mechanism

For proper body function two opposing systems are needed: if there are accelerators there must be inhibitors. Muscles, for example, work in antagonistic way (when one kind of muscle contracts the other relaxes). Same is the case with hormones. If one hormone promotes or stimulates, there should be another hormone checking it, otherwise balance or equilibrium could not be maintained. Such a kind of interaction by the hormones to maintain a balance is mainly due to feedback mechanism as in the case of certain machines. In this system a certain 'information is 'feedback' to a source about certain events that have been carried out so that output should be adjusted accordingly. This system specially implies for the interaction between the pituitary and other glands which it controls. For example, thyroid-stimulating hormone of the pituitary stimulates thyroid to produce thyroxine and when a reasonable amount of the latter has been secreted, futher production will be kept in check, as thyroxine reaches the pituitary via circulation and production of TSH is suppressed. The 'feedback' of thyroxine to pituitary regulates the output of the latter. It is just like a thermostate which is set at a definite temperature, when that temperature is reached it is shut off and when the temperature begins to decrease than a set temperature, it is turned on again automatically so as to restore the temperature. By taking another example, the follicle-stimulating hormone (FSH) of the pituitary stimulates the production of estrogen by the ovary and then the secretion of the former is inhibited by the negative feedback mechanism because when estrogen reaches a certain level in the blood it suppresses the secretion of FSH. This kind of feedback also helps in homeostasis. For example, if the blood sugar level rises, the pancreas is stimulated to secrete insulin which remove glucose from the blood, and a fall in sugar level to normal, suppresses the insulin production.

QUESTIONS

1. Why is there a need for a central coordinating system? What are the elements of such a system?
2. In what way is the nervous system of a planarian considered more highly developed than that of *Hydra*?
3. Trace by means of diagrams and description the possible reflex arc in (a) sneezing, (b) watering of the mouth.
4. What is the relationship between coordination and homeostasis? Which kind of coordination, do you think, is involved in the latter?
5. If all nerve impulses, whether from the skin or eyes, ears or nose, are the same in their electro-chemical nature, transmission and potential then how is it that they can be distinguished as touch or sight, sound or smell?
6. How are neurons different and similar to other body cells? Inspite of the fact, that they are meant for conduction they are not physically connected with each other, what do you think is the advantage or disadvantage of this?
7. List all the similarities and differences between nervous control and hormonal control.
8. How does the breathing centre in the human brain cope with the different situations so as to bring about regulation or homeostasis?
9. Explain the role of the pituitary gland as the master gland.

SUPPORT AND LOCOMOTION

6

Locomotion is defined as the movement of an organism as a whole from place to place. It is a characteristic that distinguishes animals from plants. Plants, with the exception of a few like slime molds, flagellated algal cells and sex cells of higher plants, are **sessile** i.e. they remain fixed to a place throughout their life. Whereas most of the animals are **motile** i.e. they can move freely from place to place. A few species of aquatic animals are sessile as they remain attached to a place throughout their life e.g. sponges, some coelenterates etc.

The sessile animals depend on the food which comes to them alongwith the water currents. These animals are, therefore, found at places where a constant and abundant food supply is available. The motile animals are at an advantage over the sessile animals as they move from place to place in order to acquire food and mate of their own choice. This mode of life also enables them to run away from their enemies and to avoid extremes of environment.

Generally, the motile animals have the same body plan i.e. they all have one end of the body that moves forward first. This end is

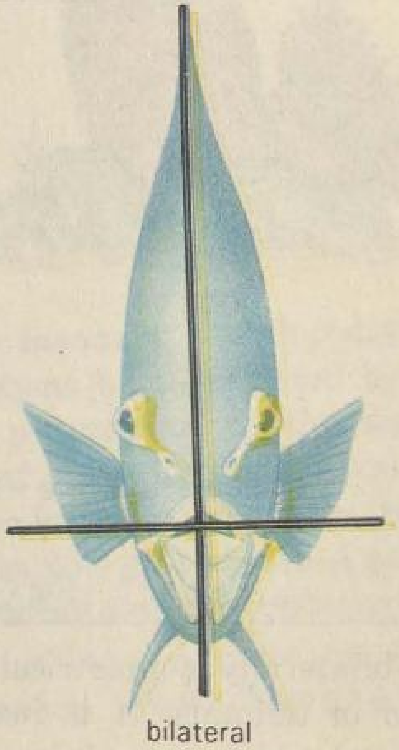
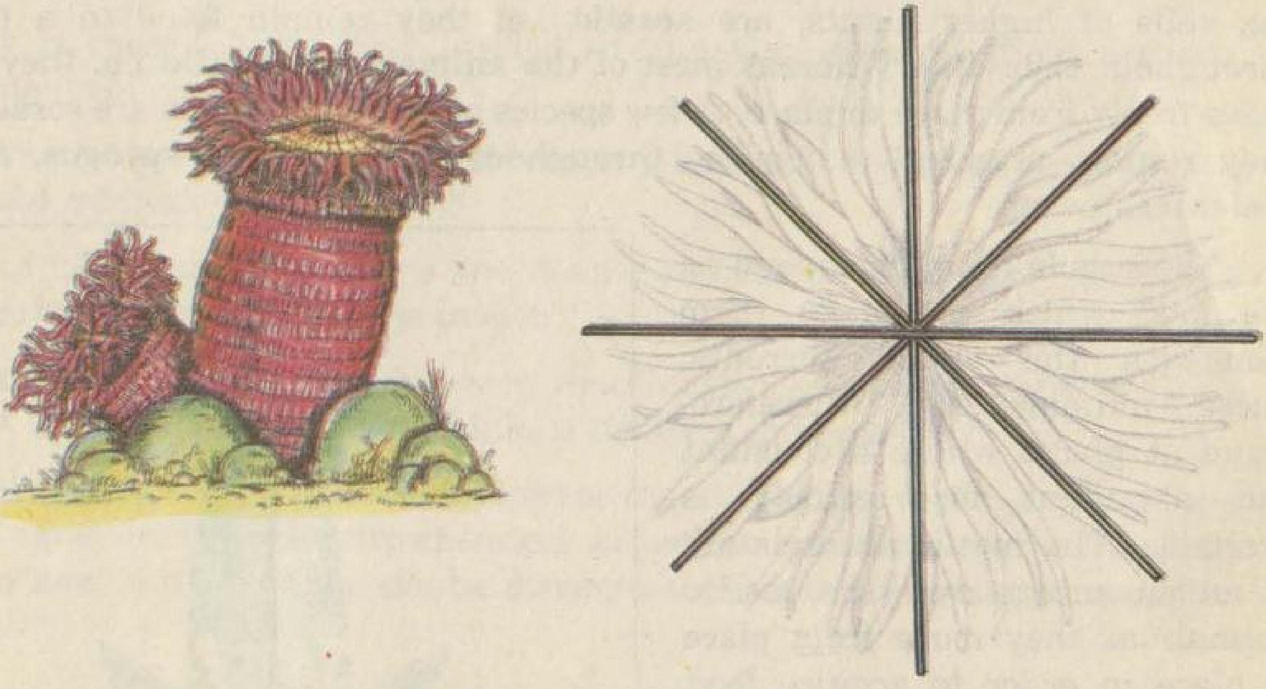


Fig 6.1. Diagrammatic representation of Bilateral symmetry.

termed as the head. It is specialized for sensing the environment. The sense organs in the head receive information from the environment and pass it on to the brain which makes the body respond accordingly. All these animals have two similar sides of their bodies. Their bodies can, therefore, be divided into two similar halves by an imaginary line passing down the middle of the animal from the head to the other end. The animals with this kind of body plan are **bilaterally symmetrical animals** (Fig. 6.1).

Some other animals have their organs arranged like a wheel around a single central point (hub) where the mouth is present. These animals are called **radially symmetrical** animals as they can be divided into two similar halves in more than one plane (Fig. 6.2). All sides of these animals are equally sensitive. Most of the radially symmetrical animals are sessile but a few like jelly fish and most echinoderms can move about slowly.



a) sea anemone - sessile animal with radial symmetry b) diagrammatic representation

Fig 6.2. Radial symmetry.

The bilaterally symmetrical body plan has played a significant role in the evolution of animals. It is interesting to know that only the bilaterally symmetrical motile animals have invaded the land. Even in the seas the most rapidly moving animals are bilaterally symmetrical.

Methods of Locomotion

Animals move about in a variety of ways and different organs are involved in their locomotion. Although *Amoeba*, earth-worm and snake apparently move by crawling but their organs and mode of locomotion are different. Similarly the locomotion of *Paramecium*, fishes and porpoises is referred to as swimming but there is a big difference in the swimming of *Paramecium* and that of fishes and porpoises. *Paramecium* moves by means of its cilia whereas fishes and porpoises utilize their muscles and skeletal elements.

The unicellular organisms like *Amoeba* and *Paramecium* have distinctly different organs of locomotion from those of multicellular organisms. It is, therefore, appropriate to study and consider locomotion at these two levels of organization.

Locomotion in Unicellular Organisms

At unicellular level of organization the locomotion is usually carried out by the evaginations or appendages of the single cell. These are of three types viz., **pseudopodia, cilia** and **flagella**. Accordingly there are three types of locomotion:

(a) Movement by using pseudopodia

(b) Movement by using cilia

(c) Movement by using flagella

Movement by Using Pseudopodia

The amoeboid movements take place by means of pseudopodia (singular pseudopodium) which are finger like projections best exhibited by *Amoeba*. Pseudopodium is formed by extension of protoplasm in the direction of movement. The pseudopodium thus formed attaches to the substratum. Then a contractile process at the forward end of the body drags or pulls the *Ameoba* in that direction (Fig. 6.3). This pseudopodium now gets absorbed and another is fomed farther off in that direction. The *Amoeba* thus moves by continuously repeating this process. The exact mechanism of the formation and working of the pseudopodia is still unknown. It is also not known how the energy is supplied for this purpose.

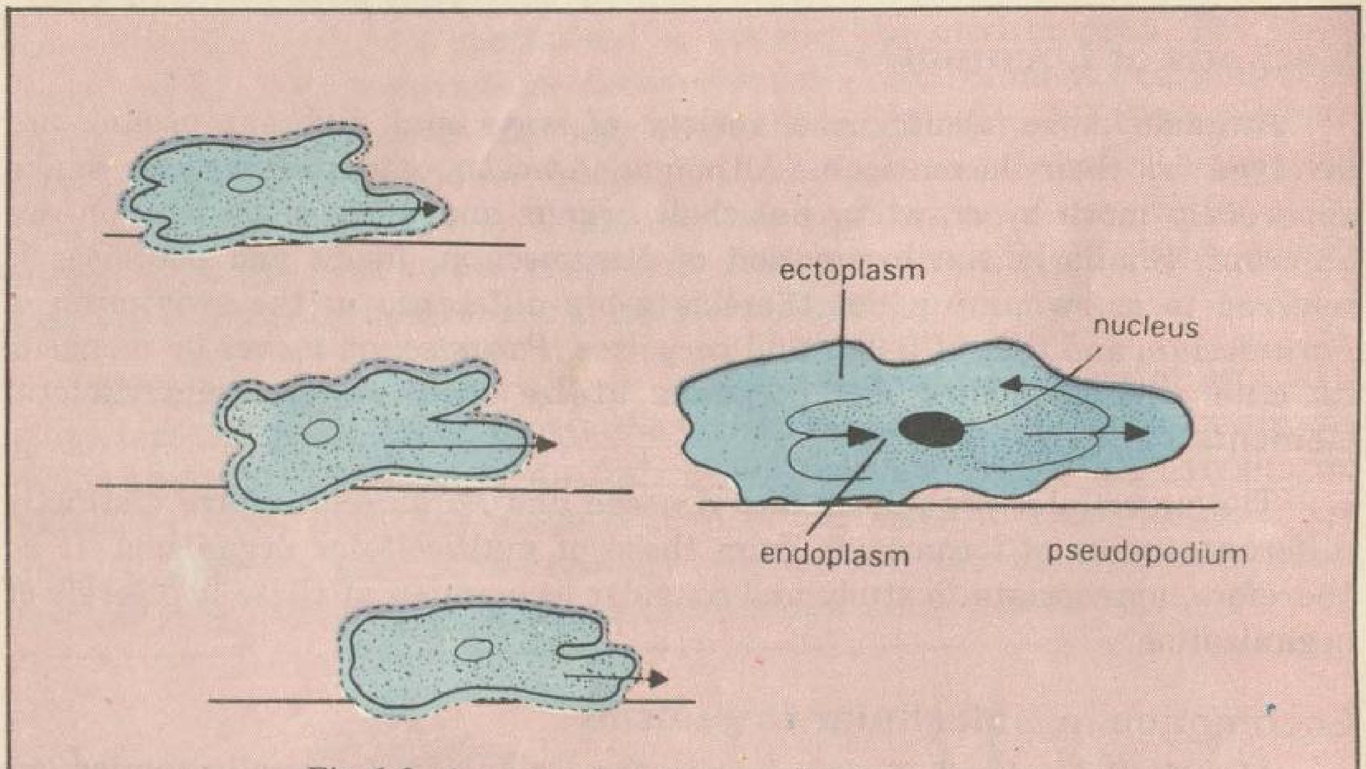


Fig 6.3. Amoeba showing amoeboid movement.

Movement by Using Cilia

The cilia (singular cilium) are short, thread like extensions of the cell membrane. They usually occur in large numbers. *Paramecium* and other ciliates swim in water with the help of cilia. Cilia may range in length from several micrometer to several hundred micrometer but their diameter is constant (0.1 to 0.5μm) (Fig 6.4)

Light microscope does not reveal the details of the internal structure of cilia. The electron microscope has shown the presence of nine peripheral double fibrils, and two central smaller fibrils, all running longitudinally through each cilium (Fig. 6.5).

The fibrils are covered with an extension of the cell membrane. The exact mechanism of bending or perhaps shortening of the cilia that produces the characteristic movement is not known. As Bradford (1955) suggested, the movement of cilia may result from contraction or sliding of double fibrils in two groups one after the other. The five out of nine double fibrils contracting or sliding simultaneously lead to the effective stroke for bending or shortening of the cilium. The other four double fibrils subsequently contract slowly to produce the recovery stroke. The energy for the movement is provided by ATP. The cilia have been found to contain enzyme that can split

ATP. This view gets further support from the fact that the poison which stops the formation of ATP stops the ciliary action.

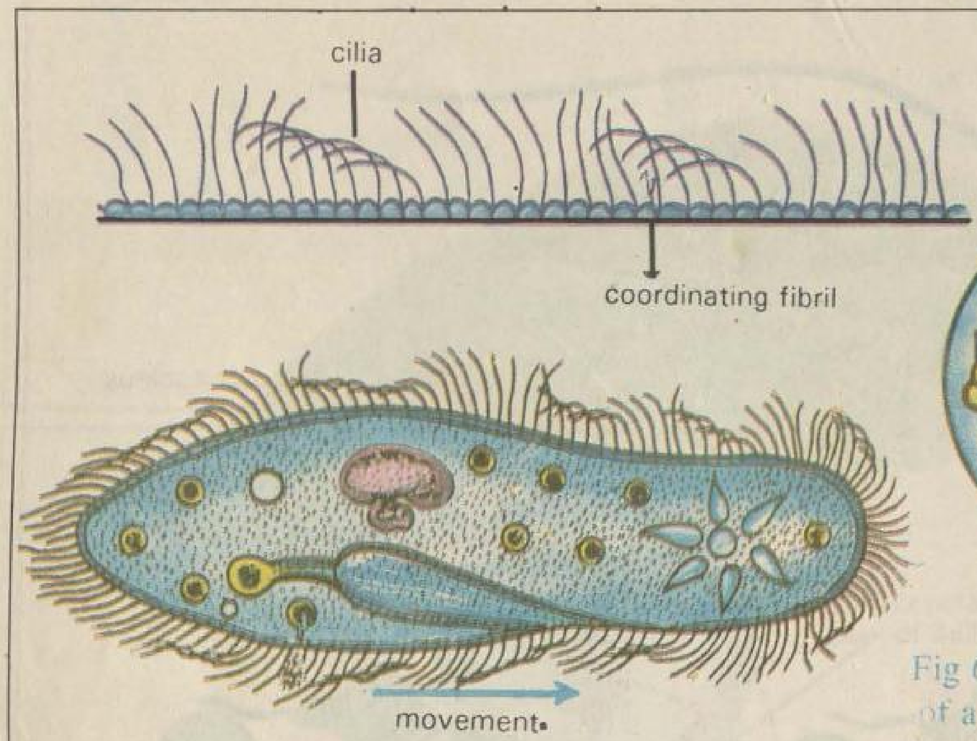


Fig 6.4. Paramecium showing ciliary movement.

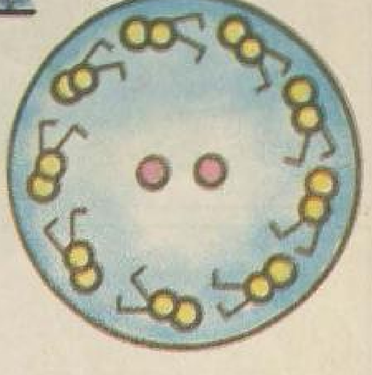
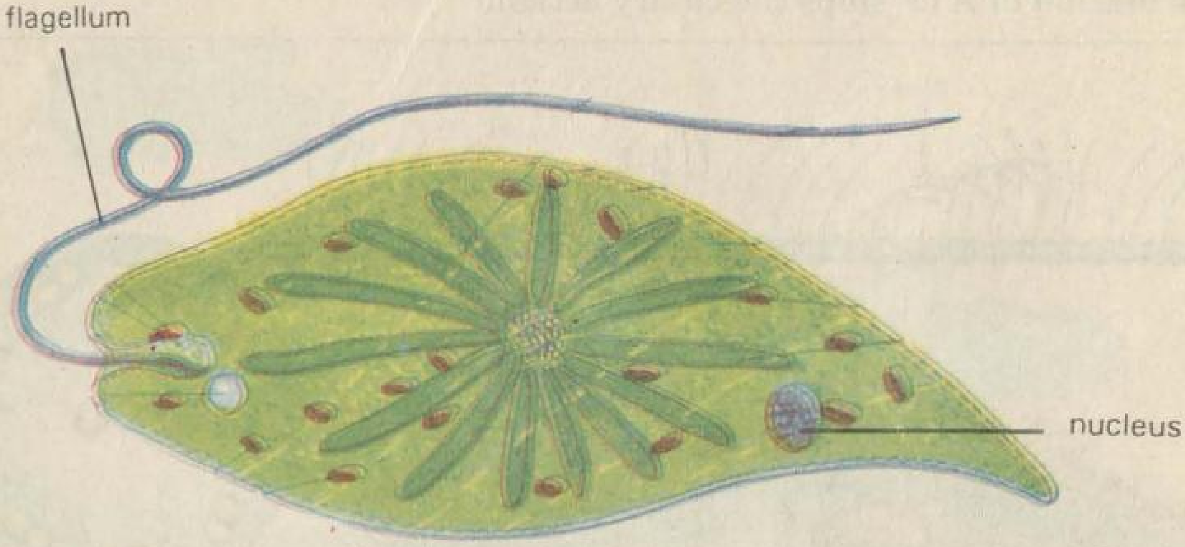


Fig 6.5. A cross - section of a cilium under electron microscope.

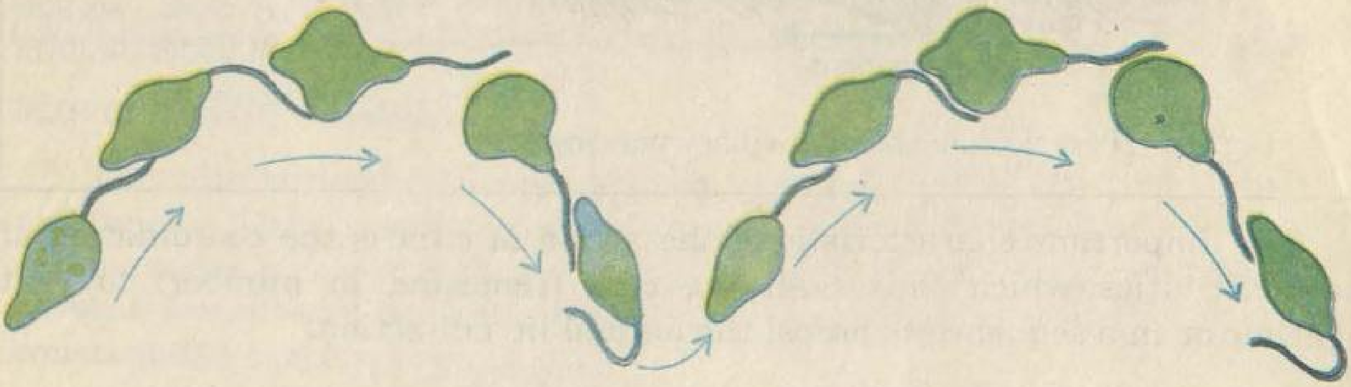
The important characteristic of the action of cilia is the coordination of their activities which causes all the cilia (thousand in number) to beat together or in a sequence to propel the animal in a direction.

Movement by Using Flagella

The flagella (singular flagellum) are similar in their structure to cilia except that they are relatively larger in size and fewer in number (flagella usually occur singly or in very small numbers). The structural similarity of flagella and cilia suggests similarity in their mechanism of action. The flagellates move by whipping action of their flagella against water. This type of movement is exhibited by *Euglena, Chlamydomonas, Volvox* etc (Fig. 6.6).



a) Euglena



b) arrows showing directions of body and flagellary movement

Fig 6.6. Euglena showing flagellary movement.

Locomotion in Multicellular Animals

In multicellular animals the locomotory organs are built on a different plan than those of unicellular organisms. Instead of being appendages of single cells, the locomotory organs of multicellular animals are formed of specialized cells, tissues and organs which work together in a coordinated way to move the animals.

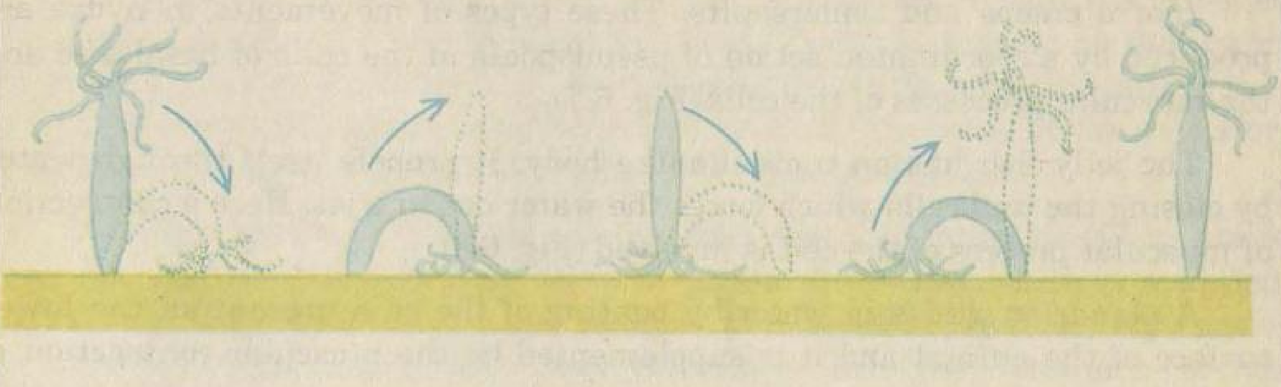


Fig 6.7. Hydra showing somersault movement.

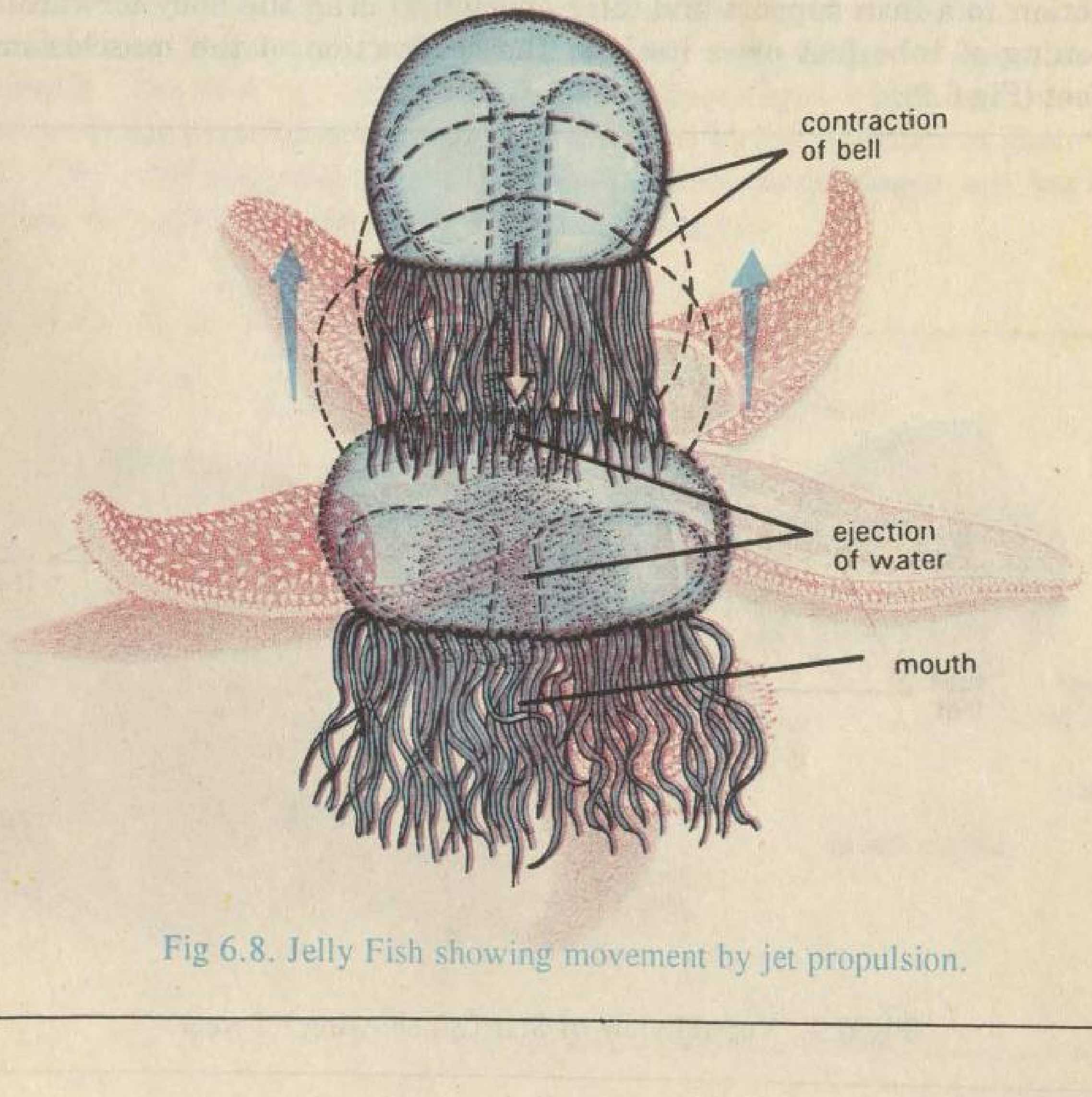

contraction of bell
ejection of water
mouth

Fig 6.8. Jelly Fish showing movement by jet propulsion.

Hydra creeps and somersaults. These types of movements in hydra are produced by a coordinated action of pseudopodia of the cells of basal disc and the muscular processes of the cells (Fig. 6.7).

The jelly fish has an umbrella-like body. It propels itself through water by closing the umbrella which forces the water out in a jet. Here a contraction of muscular process of the cell is involved (Fig. 6.8).

A planarian glides in water by beating of the cilia present on the lower surface of the animal and it is supplemented by the muscular contraction of the body.

The starfish and related animals move by means of their tube feet. The tube feet extend on water being pumped into them, then they fix themselves by suction to a firm support and later shorten to drag the body forward. The shortening of tube feet owes itself to the contraction of the muscles in the tubefeet (Fig 6.9).

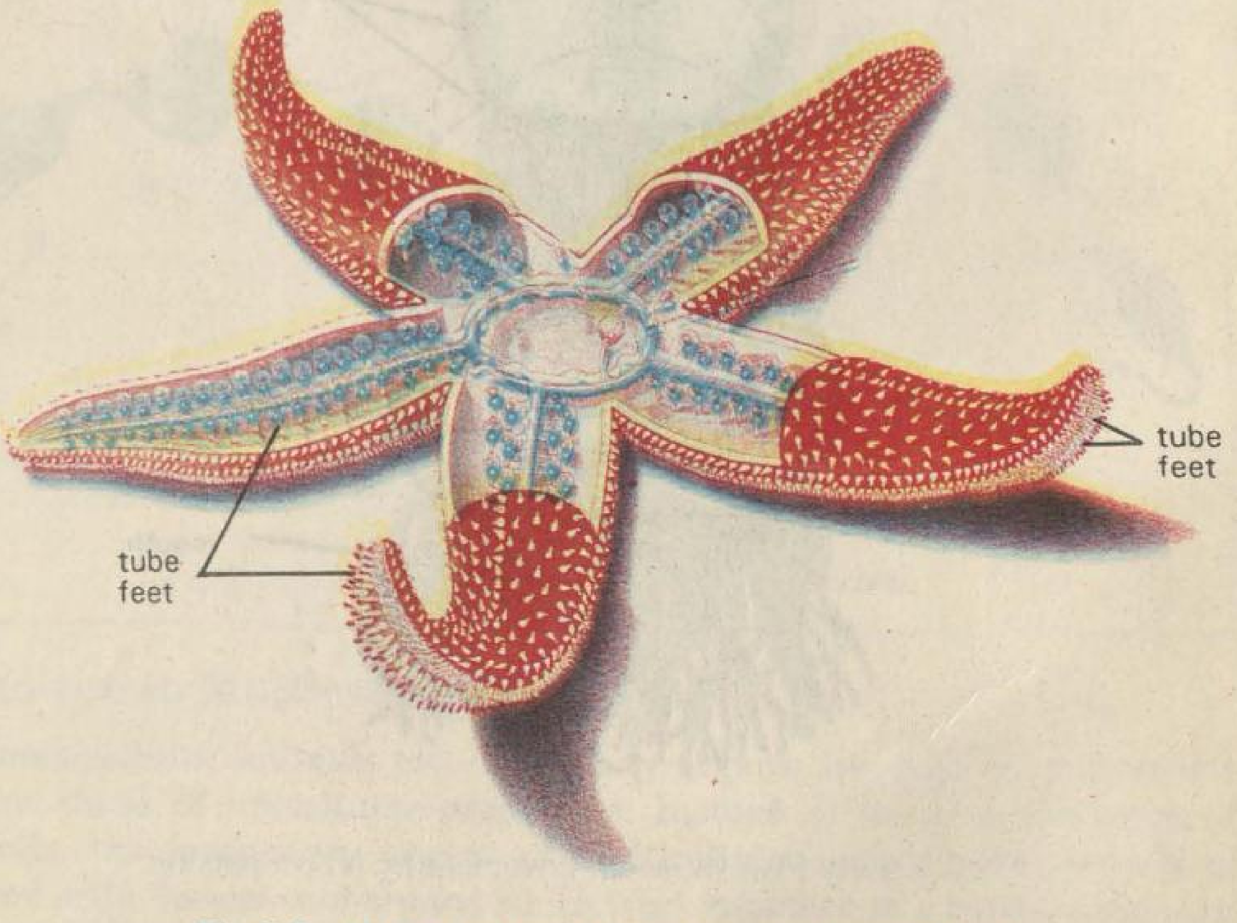
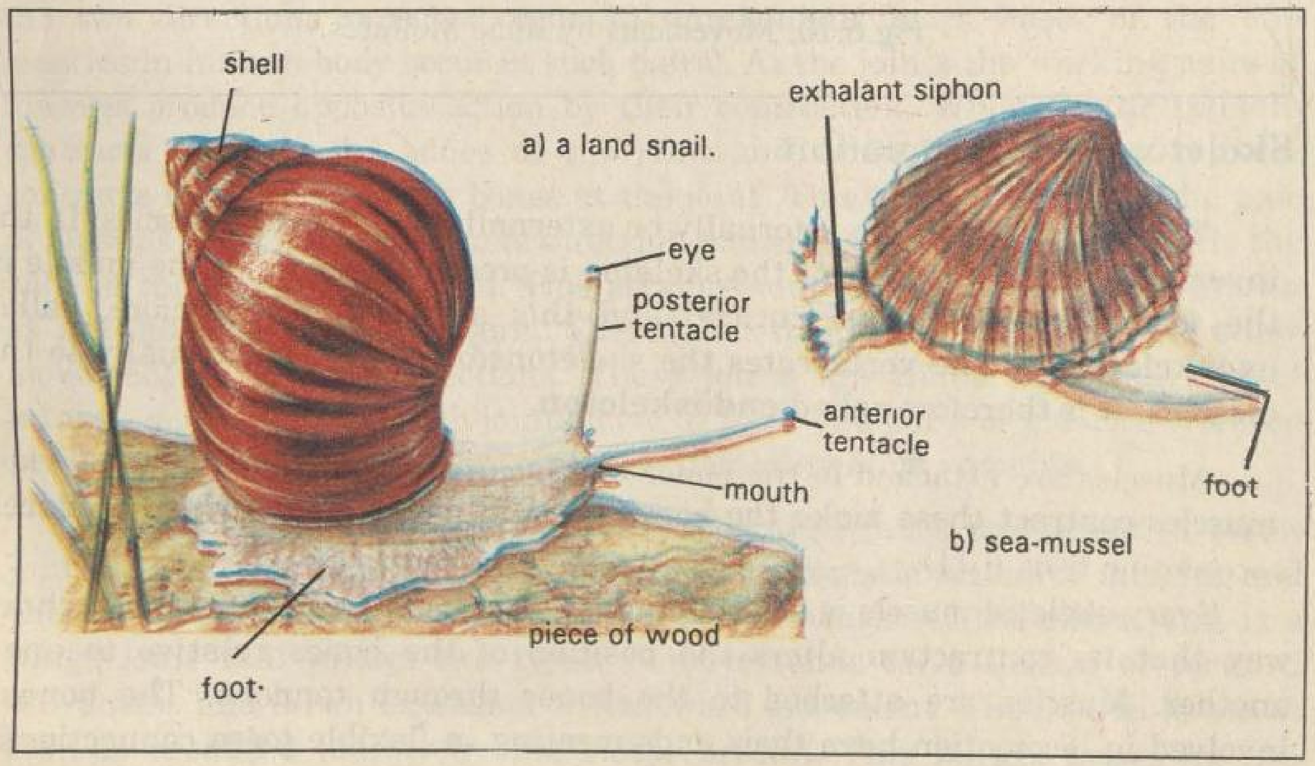


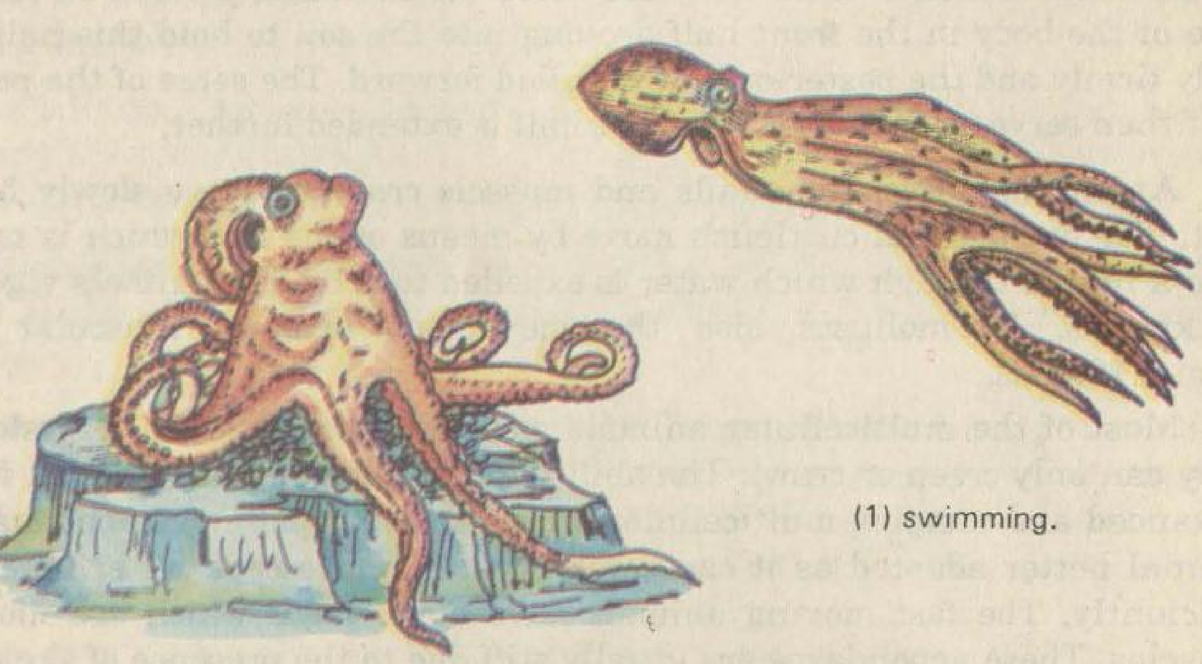
Fig 6.9. Ventral view of Star fish showing tubefeet.

An earthworm shows an accordion-like movements in which the setae (bristles) and muscles of the body are involved. The setae present on the lower side of the body in the front half are dug into the soil to hold this half of the body firmly and the posterior half is pulled forward. The setae of the posterior half then serve as anchor as the front half is extended further.

Among molluscs, the snails and mussels crawl or move slowly by their foot. The octopus and cuttlefish move by means of the foot which is modified into a funnel through which water is expelled to drive the animals vigorously backwards. In molluscs also the movement involves muscular action (Fig. 6.10a,b,c).

Most of the multicellular animals mentioned so far move very slowly as they can only creep or crawl. The ability to move rapidly has evolved in more advanced and complex multicellular animals. The rapid movement makes an animal better adapted as it can catch its prey and escape its enemies more efficiently. The fast moving animals have appendages which are moved by muscles. These appendages are usually stiff due to the presence of skeleton in them. The stiff appendages act as levers. These appendages are variously modified for walking, running, swimming, flying etc.





(1) swimming.

(2) attached to a rock by the suckers of the arm.

(c) octopus

Fig 6.10. Movements by some Molluscs.

Skeleton and Locomotion

The skeleton may lie internally or externally to the body muscles. In the invertebrates e.g. arthropods the skeleton is present external to the muscle in the form of rigid plates (cuticle) and this skeleton is, therefore, called **exoskeleton.** In the vertebrates the skeletons(or bones)lie internally to the muscles. It is therefore called **endoskeleton.**

Muscles are attached to the bones or the cuticle in such a way that when muscles contract these make the bones or rigid plates move, which produces locomotion (Fig. 6.11).

Every skeletal muscle is attached to at least two different bones in such a way that its contraction alters the position of the bones relative to one another. Muscles are attached to the bones through tendons. The bones involved in locomotion have their ends meeting in flexible loose connections called **joints** where the bones are held together by a tissue called **ligament.** Many joints such as elbow and knee joints are hinge joints that allow

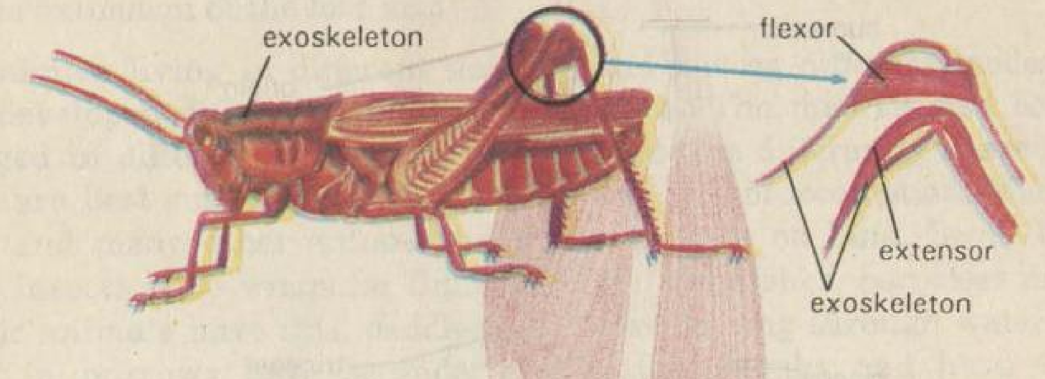


Fig 6.11. A Grasshopper has an exoskeleton and showing muscle attachment.

movement in two dimensions only. At these joints pair of muscles are arranged in roughly the same plane as that of the joints. One end of each muscle (the origin) is fixed to an immovable bone on one side of the joint and the other end of the muscle (the insertion) is attached to the far side of the joint to another bone which is usually movable. To allow a bone to move in the two directions muscles occur in antagonistic pairs (most of the 650 muscles in human body occur in such pairs). At the joints the working pairs of muscles produce opposite action by their contraction. When **flexor muscle** contracts it bends the bones at the joint and when the **extensor muscle** contracts it straightens the bones at the joint. This is because one of the pair of muscles pulls the bone in one direction and the companion muscle pulls the bone in the opposite direction. This arrangement of skeletal muscle is known as **antagonistic arrangement**. There are other types of joints that allow movement in several directions. These joints are called **ball** and **socket joints e.g., hip joints**. Such joints have at least two pairs of muscles oriented perpendicularly to each other to provide flexibility of movements.

A study of the arrangement of muscles that cause movement at elbow joint in man will help to understand the antagonistic action of muscles and the movements produced thereby. As already mentioned the elbow joint is a hinge joint that allows two types of movements: (1) a flexion or forward movement and (2) an extension or backward movement. The flexion at elbow joint is produced mainly by the biceps brachii. This muscle arises by two heads from the scapula and it inserts into the medial surface of the radius. In addition to this big muscle there are two other flexor muscles: (1) the **brachialis** and (2) the **brachioradialis**. The brachialis lies under the biceps

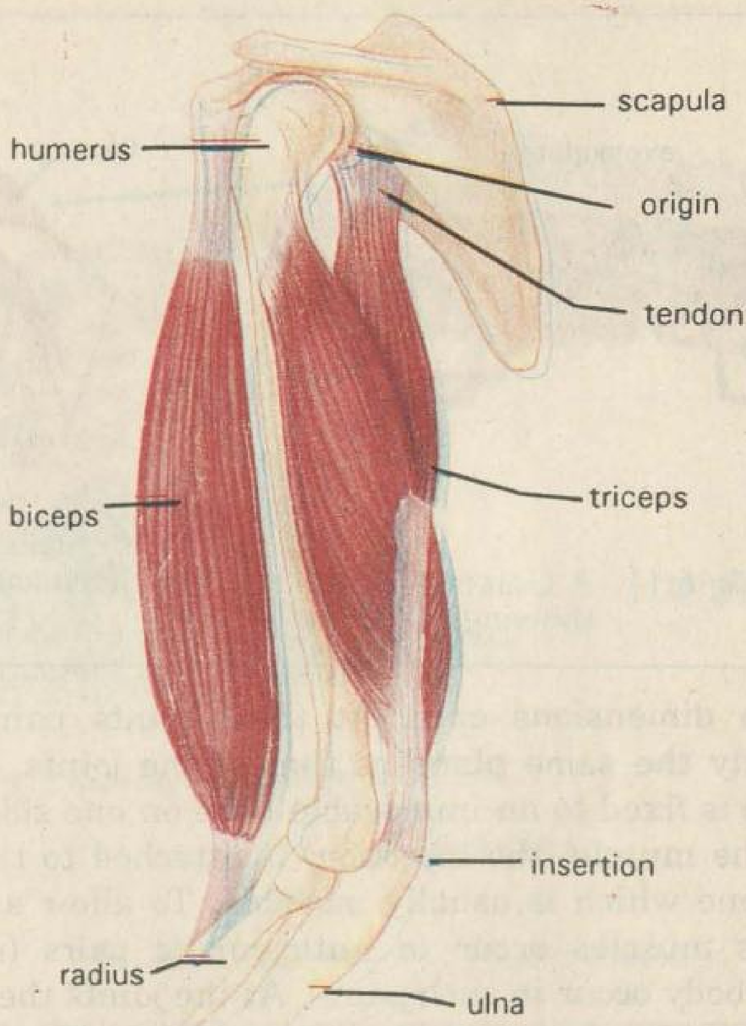


Fig 6.12. Attachment of muscles at elbow joint.

brachii. It arises from the anterior surface of the lower three fifths of the humerus and inserts into the ulna slightly in front of the elbow joint. The brachioradialis arises from the lateral side of the lower end of the humerus and after extending most of the length of the forearm it inserts into the lateral border of the distal shaft of the radius. Thus the biceps brachii and brachioradialis lift the radius on their contraction at the same time the brachialis lifts the ulna (Fig. 6.12).

The only muscle that causes extension at elbow is the big and powerful **triceps brachii**. It has three heads: (1) a long head that arises from the scapula below the shoulder joint (2) a lateral head that arises from the lateral surface of the humerus and (3) a medial head arising from the medial and posterior surface of the humerus. All these heads fuse at their lower end and insert through a common tendon on the olecranon process of the ulna. This muscle on contraction exerts a powerful force on the upper end of the ulna to produce extension of the fore arm.

Animals living in different habitats and having different modes of life have developed different organs of locomotion. The muscles and bones are arranged in different patterns in them to produce differently shaped organs which are best suited to perform the specific type of locomotion. Man, horse, cattle and many other animals have legs to walk on land. Birds, bats and flying insects have wings for flight through air. Fishes, porpoises and other aquatic animals have fins, paddles etc. for swimming through water. Snakes living in burrows have secondarily lost their limbs and have taken to crawling on their bellies. Various animals that live on trees, like certain monkeys, have prehensile tail and opposable thumb to grip the twigs etc.

Skeletal Muscles

The muscles, that are attached to the skeleton and are associated with the movements of bones, are called **skeletal muscles**. There are two other types of muscles in the body, which are known as **cardiac muscles** and **smooth muscles**. These muscles are involuntary in their function and are generally controlled by hormones and autonomic nervous system. The skeletal muscles, on the other hand, are consciously controlled and are, therefore, voluntary muscles. These muscles generally contract on receiving impulses from the central nervous system. The skeletal muscles, as compared to the cardiac and smooth muscles, contract relatively quickly and are fatigued easily.

The skeletal muscles are also known as **striated muscles**. Striated means striped, and this term is used because each skeletal muscle fibre when viewed under the microscope shows numerous bands of alternating dark and light regions.

A skeletal muscle fibre is about 10-100 μ in diameter and may sometime be as long as 30 cm running the entire length of the muscle. Each muscle fibre in turn contains great many (1000 to 2000) individual contractile subunits, extending from one end of the fibre to the other, which are called the **myofibrils**. The fibre itself is enclosed in a cell membrane or (sarcolemma). Under this membrane lie nuclei one at every 5 μ along the length of the fibre.

Each myofibril is packed with myofilaments, the so called thin and thick filaments which run longitudinally within the sarcoplasmic envelope. These

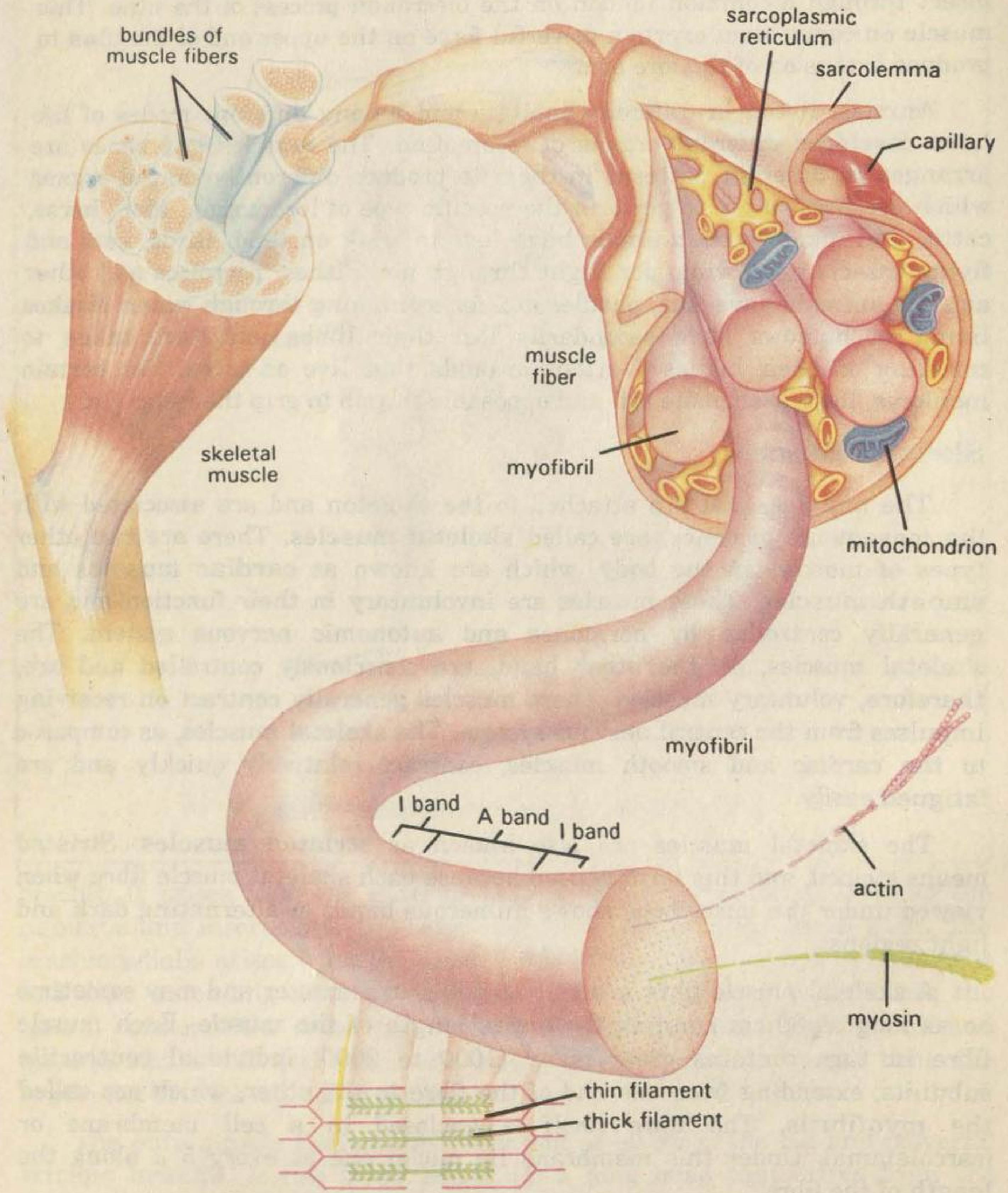

bundles of muscle fibers
sarcoplasmic reticulum
sarcolemma
capillary
muscle fiber
skeletal muscle
myofibril
mitochondrion
myofibril
I band
A band
I band
actin
myosin
thin filament
thick filament

Fig 6.13. Structure of a skeletal muscle.

thick and thin filaments are made up of proteins called **myosin** and **actin** respectively (Fig. 6.13). Each thick or thin filament does not run the entire length of the myofibril. Instead these filaments run for short distance along the length of the myofibrils and are repeated longitudinally to divide the myofibrils into segments called **sarcomeres**. Each sarcomere is enwrapped by vesicles of sarcoplasmic reticulum and an invagination of sarcolemma in the form of T-tubules extends and encircles the myofibrils at the level of Z-line or A and I junction. The T-tubule and the terminal portions of the two adjacent envelops of sarcoplasmic reticulum form a **triad** at regular intervals along the

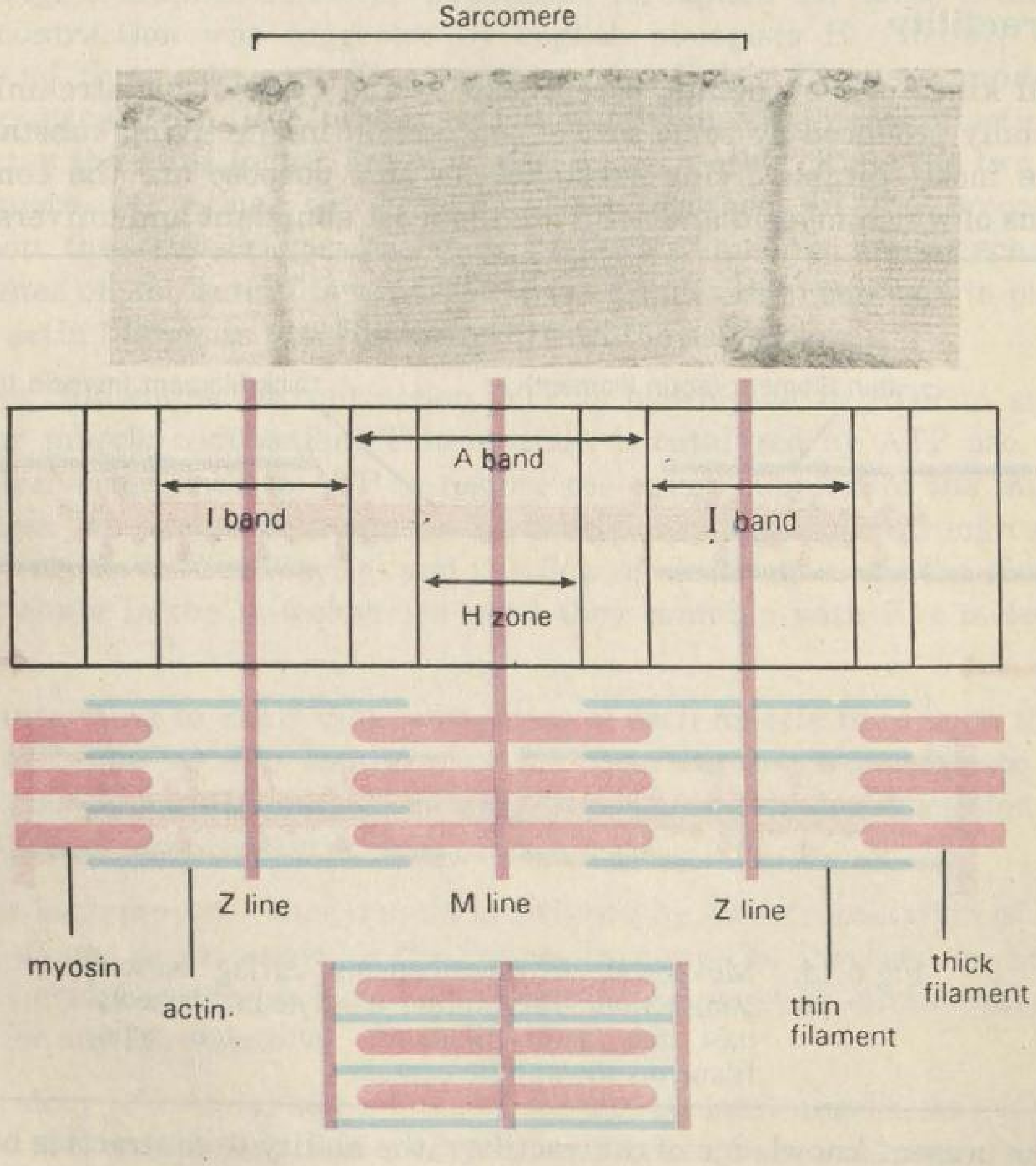

Sarcomere
A band
I band
I band
H zone
Z line
M line
Z line
myosin
actin
thin filament
thick filament

Fig 6.14. Structure of a sarcomere.

length of the fibrils.

The spatial arrangement of thick and thin filaments in a sarcomere gives rise to the characteristic cross striated pattern. The less dense filaments of actin give rise to the light I band and the myosin filaments more or less overlapped by actin filaments to the denser A band. The thin filaments or actin filaments themselves arise from z discs which appear as thin lines. Z discs contain actin and also other proteins; the most abundant being the tropomyosin (Fig. 6.14). The thick filament have cross bridges sticking out towards the actin filaments at the ends of the thick filament.

Contractility

All kinds of movements, except growth and cytoplasmic streaming, are essentially produced by some sort of contraction in the living substance. By far the most suitable living substance for this purpose are the contractile proteins of which myosin and actin are the most abundant and universal.

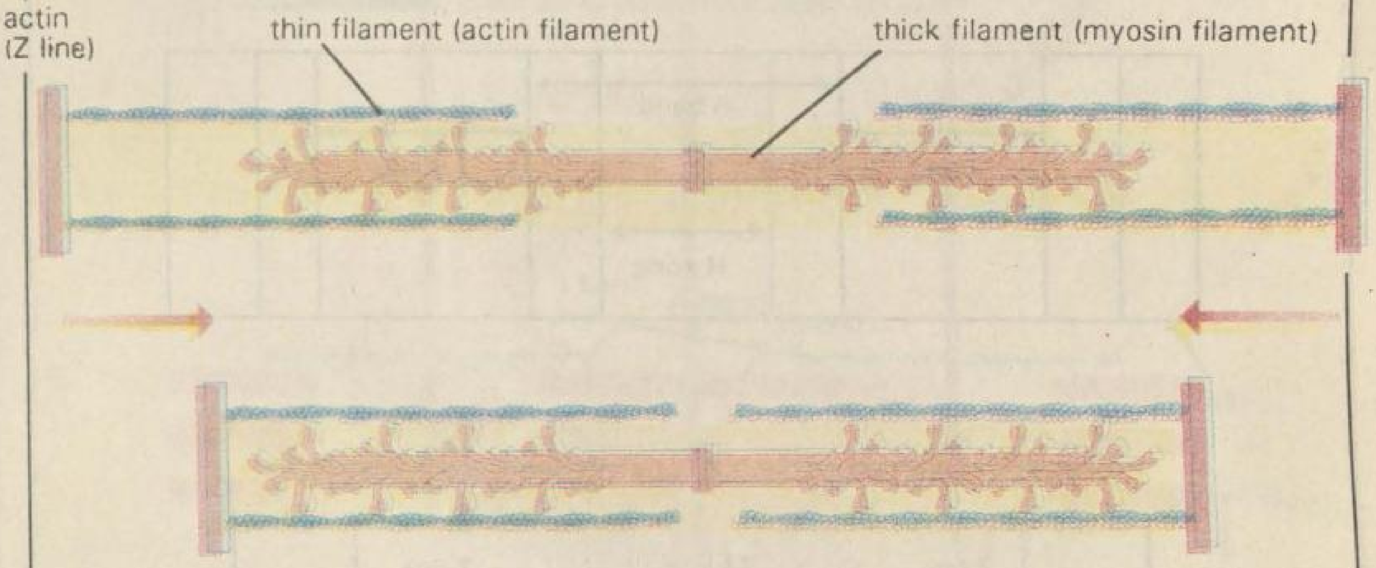

actin
(Z line)
thin filament (actin filament)
thick filament (myosin filament)

Fig 6.15. Movement of myofilaments during muscle contraction. The sliding of myosin filaments past the actin filaments pulls the actin filaments toward the center.

The present knowledge of contractility (the ability to contract) is based on the studies of vertebrate skeletal muscles. A muscle fibre contracts on recieving an impulse from the nerve supply to the muscle. The impulse is carried from the sarcolemma to every myofibrils by the T-tubules. The impulse releases Ca^{++} ions from the sarcoplasmic reticulum which triggers the muscle contraction. The Ca^{++} ions are pumped back into sarcoplasmic reticulum. When the muscle cell contracts, the thin and thick bands undergo some shifting. The I bands are reduced in their length to varying degrees depending upon the extent of shortening of the muscle. These changes are produced by the z lines getting closer together in all the contracting myofibrils due to sliding of the thick and thin filaments over each other. But the filament of myosin and actin do not contract in the sense that they get any shorter. The filaments surprisingly preserve their individual initial length (Fig. 6.17a,b,c). A clever hypothesis to explain all these events in muscle contraction was suggested by english biologists H. Huxley, A. F. Huxley and their collegues. This is known as **sliding filament model of muscle contraction.** It postulates that the individual filaments of actin and myosin stay the same length but slide past on each other. Thus the two ends of sarcomere i.e. z-lines are brought cross together. In the process of contraction the cross-bridges or bands of thick filaments are attached to binding sites on the actin filament. The cross bridges then contract to pull or push the actin filaments towards the centres of the sarcomere.

During the course of contraction ATP is hydrolysed to ADP to supply energy for muscle contraction. This reaction is catalyzed by ATP ase. This must be converted back to ATP to restore the enrgy supplies of the muscle. This process you may recall requires the breakdown of glucose through many steps (Glycolysis & Kreb's cycle) and the flow of electrons along the electron transport chain in the mitochondria until they combine with free molecular oxygen.

It is intersting to know that contraction of each muscle fibre is on the all or none principle i.e if it contracts at all, then its fibrils participate. The reason a muscle can contract to varying degrees, is that a contraction may involve a few, a considerable or most of its fibres.

It has been proposed that muscle is fatigued by the accumulation of lactic acid. We do not as yet know all the factors that may be involved in fatigue. The lactic acid, however, is harmful to the cell and must be eliminated if not oxidized for any long time.

This story of contractility described for the skeletal muscle may equally apply to the contraction and recovery processes of smooth, involuntary muscles. In fact this may be the fundamental mechanism involved in all types of contractions, because glucose, ATP and proteins similar to myosin and actin play a universal role in all animals from amoeba to man.

Skeleton And Support

The skeleton is the framework about which the body is built. It, therefore, provides support for the soft parts of the body and also determines the shapes of the various parts of the body.

The cranium encases and supports the brain. In man it is formed of eight bones: (1) The frontal bone, (2) the occipital bone, (3) and (4) two parietal bones, (5) and (6) two temporal bones, (7) part of the sphenoid bone and (8) part of the ethmoid bone.

The facial bones support the face. The names of these bones in man are (1) maxilla, (2) zygomatic bone, (3) nasal bone, (4) part of the ethmoid bone, (5) part of the sphenoid bone, (6) lacrimal bone, (7) vomer, (8) palatine bone and (9) inferior concha.

The mandible provides the framework and support of the lower jaw.

The vertebral column in man consists of 33 vertebrae. The vertebral column supports the weight of the body and provides axial support to the head. The seven anterior vertebrae lie in the neck region and are called the **cervical vertebrae.** Of these the first two vertebrae are different in their shape and structure from each other and from the rest of the vertebrae. These are called **atlas vertebra** and **axis vertebra** repectively. The next 12 vertebra lie in the thoracic region and are called **thoracic vertebrae.** The still next 5 vertebrae lying the lower back are called **lumber vertebrae.** The posterior 9 vertebrae are present in the pelvic region. Of these nine, the five anterior are fused together to form the **sacrum** and the posterior four are fused to form the **coccyx.**

The **chest cage** (also called chest box, thoracic cage or rib cage) is comprised of twelve pairs of ribs that articulate posteriorly with the thoracic vertebrae. Ten of them also connect anterior with the sternum either directly or through the costal arch. This cage provides support for a semivacuum chamber called the chest cavity (Fig. 6.16).

The **pectoral girdle** attaches the arms to the trunk and it is comprised of the scapula and the clavicle. The clavicle is a weak bone that connects the scapula to the sternum. This bone acts more as a guide for scapular movements than a support structure.

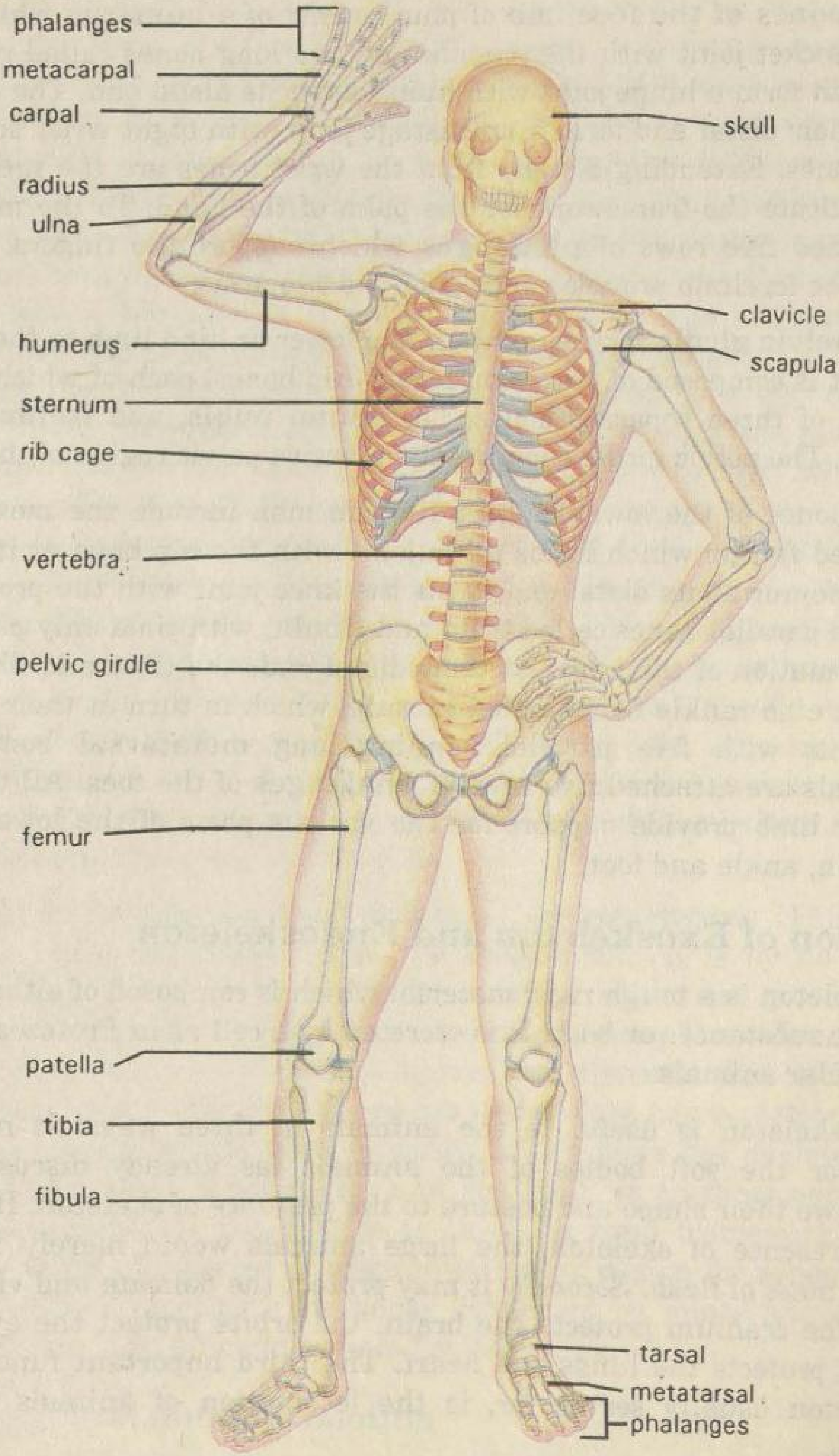

phalanges
metacarpal
carpal
radius
ulna
humerus
sternum
rib cage
vertebra
pelvic girdle
femur
patella
tibia
fibula
skull
clavicle
scapula
tarsal
metatarsal
phalanges

Fig. 6.16. Anterior view of the entire human skeleton.

The **bones of the forelimb** of man consist of a **humerus** which forms a ball and socket joint with the scapula and two long bones called **radius** and **ulna** which form a hinge joint with humerus at its distal end. The radius and ulna at their distal end form a multistage joint with eight wrist bones called **carpel** bones. Extending distally from the wrist bones are the **metacarpals** that constitute the framework for the palm of the hand. To the metacarpals are attached five rows of **phalanges** which support the fingers. All these bones of the forelimb provide support for the two arms.

The **pelvic girdle** serves to attach the lower or hind limb to the vertebral column. It is composed of two coxal bones (hip bones) each of which is formed by fusion of three separate bones, i.e. **illium, pubis,** and **ischium,** during foetal life. The pelvic girdle supports the massive pelvic region of the body.

The bones of the lower or hind limb in man include the most proximal bone called **femur** which forms a hip joint with the hip bone at its proximal end. The femur at its distal end forms the knee joint with the proximal ends of the two parallel bones called **tibia** and **fibula**, with tibia only participating in the formation of the joint. At their distal ends the tibia and fibula form a joint with eight ankle bones called **tarsals**, which in turn at their distal ends form joints with five parallel running long **metatarsal** bones. To the metatarsals are attached five rows of **phalanges** of the toes. All the bones of the lower limb provide support for the various parts of the lower limbs i.e. thigh, shin, ankle and foot.

Evolution of Exoskeleton and Endoskeleton

A skeleton is a tough rigid material which is composed of either inorganic or organic substances or both. It is secreted by a cell as in Protozoa, cells as in multicellular animals.

The skeleton is useful to the animals in three ways: It may provide support for the soft bodies of the animals (as already discussed). Large animals owe their shape and posture to the presence of skeleton. If it were not for the presence of skeleton, the large animals would merely be heaps of irregular mass of flesh. Secondly it may protect the delicate and vital internal organs. The cranium protects the brain, the orbits protect the eyes and the chest box protects the lungs and heart. The third important function, which the skeleton usually serves for, is the locomotion of animals (as already discussed).

The skeleton may be external or internal depending on the position it occupies in the body. The former type of skeleton is known as **exoskeleton** and the latter type is called **endoskeleton.** The exoskeleton is primitive and is found usually in primitive animals i.e. mostly the invertebrates. This skeleton is inert and non living. It is secreted by the ectodermal cells in multicellular animals. The exoskeleton is usually very rigid and heavy, and it encases the body completely. It, therefore, restricts the animal's movements to the extent that the animals possessing it must lead a very slow moving life or even a sessile life (corals). A group of animals i.e. the arthropods, have however solved the problem, posed by the rigidity and weight of exoskeleton, very successfully. These animals are encased completely in a very light waxy substance known as **chitin.** Moreover, their exoskeletons are divided into several distinct segments which are movably attached to each other. These animals have thus beautifully combined the relative ease of motion with a protective outer covering. This is one of the reasons for the biological success of this group. Even, this type of exoskeleton possesses one great disadvantage as it does not allow for the growth of the animal. If such an animal has to grow it has to cast off (moult) and resecrete its exoskeleton periodically. The animal grows in the intervals. During these periods the animals, when they have shed their old skeleton and have not yet formed the new skeleton, run the risk of being attacked by other animals. In insects moulting usually occurs during immature stages. The adults having attained their maximum size do not undergo moulting any further.

The vertebrate animals have developed **endoskeletons.** This type of skeleton has many advantages over the exoskeleton: It is by no means a hindrance to the growth of animals. The internal bones can grow with the growth of the body as these bones contain living tissues. These bones contain bone cells which form the fibers and deposit the minerals that make up the bones. The bones like other body tissue are under close homeostatic control by hormones and other factors. The minerals of the bone get depleted during disease or long periods of inactivity and are built up to their normal level when exercise begins or the disease is cured. A rigid framework of bones sheathed in layers of muscles in apparently a good design for supporting and holding an animal together. The bones connected by joints and moved by muscles form the most efficient system for locomotion.

Internal Skeleton and Locomotion

The fossil record gives us a fairly clear history of the development of the skeleton in various groups of vertebrates. The earliest vertebrates were fish

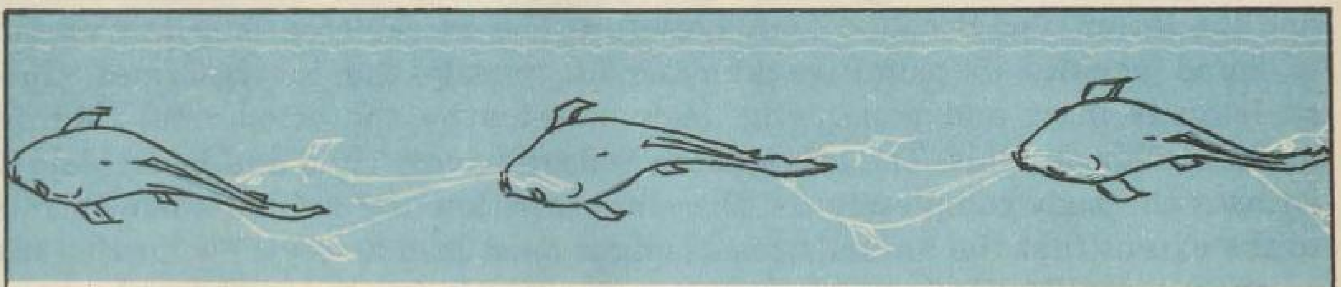
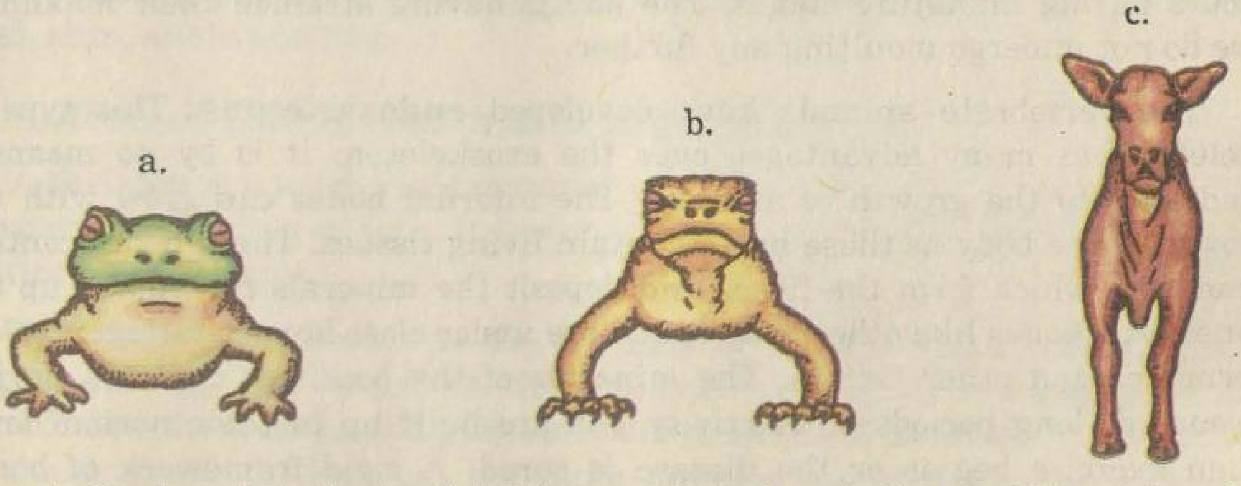


Fig. 6.17. Fish swimming movements

which possessed various adaptations for swimming. The oldest fishes i.e., the jawless fish swam by undulating their bodies from side to side. The undulating movements were porduced by alternating waves of muscle contractions passing along either side of the animal. These undulations were transmitted through the posterior part of the body and tail as a series of powerful backward pushes against the dense water. For a movement of this type a flexible back bone (vertebral column) is required. The vertebrae of fishes generally lack articulations or processes for locking the individual bones together (Fig. 6.17).



a) The legs of the first land inhabiting vertebrates i.e. primitive amphibian projected laterally from the body and then down.
b) The legs of reptiles are about intermediate in position.
c) In mammals the legs project straight down which is the most efficient way of supporting the body.

Fig 6.18. Land vertebrates showing evolution in body support.

The lobe-finned fishes, another group of earlier fishes had their paired fins supported by a series of bones arraged in a particular way which can be regarded as the beginning of a tetrapod limb. It had a single proximal long bone, two middle long bones and several bones all side by side at its distal end of its fin. These fins, however, served primarily as steering device and rudders.

Lobe-finned fishes were the ancestors of four legged amphibians. These amphibians faced the problem of gravity on land. Their legs sprawled out from the body so that the animal probably dragged itself over the ground. Most of their energy would have to be spent just in holding up the weight of the trunk if it did not rest on the ground. This problem of gravity arose with the advent of terrestrial life because it was of little consequence to water living vertebrates. The vertebrae in amphibians became complex with interlocking articulations and reasonable flexibility to support the body weight.

Early reptiles also had the same type of locomotion with their legs spreading out of the body in the same plane. However, quite early in the reptilian evolution there were trends toward bringing the legs beneath the body and thus raising the body clear of the ground and the legs acting as props. This arrangement of the legs to the body led efficiently to walking and running types of locomotion in reptiles and mammals (Fig. 6.18).

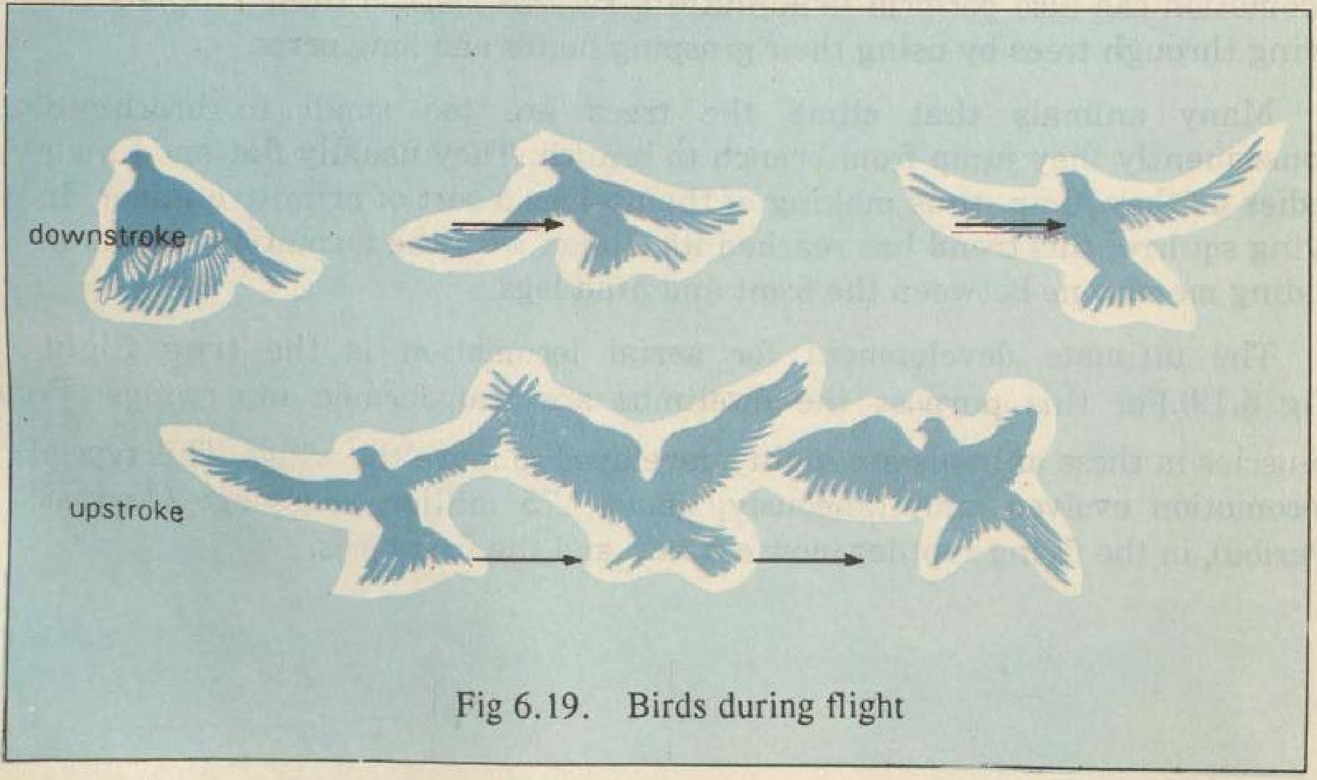


Fig 6.19. Birds during flight

In mammals, the limb bones have undergone modification to produce three forms of locomotion which have progressively produced swiftness in their locomotion. Some mammals like monkeys, apes, man, bears etc. walk on their soles (**plantigrade**) with palm (and sole), wrist (and ankle), digits (hand and foot) all tending to rest more or less on the ground. This is a primitive form of locomotion. Some other mammals like rabbits, rodents, many carnivores etc. tend to rest their digits only (**digitigrade**) on the ground with the wrist (and ankle) and palm (and sole) elevated. Digitigrade mammals run faster than the plantigrade mammals. They also walk more silently and are more agile. In these mammals the first digit is usually reduced or completely lost.

Another group of mammals walk on the tip of their toes which are hoofed. The weight of the body is supported on the tip of toes. In these cases the palm and sole, the wrist and ankle and the digits of hand and foot are elevated with only tips of digits resting on the ground. This type of locomotion is called **unguligrade** and is found in horse, goat, deer etc and it is the most swift type of locomotion.

Some mammals e.g. man, apes etc. have through the ages evolved the bipedal locomotion. They walk, run or hop on their hind limbs. Such a type of locomotion commonly releases the fore limbs for feeding and other activities. Some of these mammals like apes, monkeys etc. in addition to this type of locomotion can also perform **brachiation**. By this method these animals can swing through trees by using their grasping hands and long arms.

Many animals that climb the trees are too small to brachiate. Consequently they jump from branch to branch. They usually flattened their bodies as they jump, thus making of themselves a sort of primitive glider. In flying squirrel this trend has reached its climax with the formation of a large gliding membrane between the front and hind legs.

The ultimate development for aerial locomotion is the **true flight** (Fig. 6.19).For this purpose the forelimbs are transformed into wings. Pectoral muscles in these animals are highly developed to move the wings. This type of locomotion evolved simultaneously, about 175 million years ago (Jurrasic Period), in the flying reptiles (now extinct) and the first birds.

QUESTIONS

1. Describe methods of locomotion in unicellular animals.
2. How do movements take place in the following animals?

(a)	*Hydra*	*(b)*	jelly fish
(b)	*Amoeba*	*(d)*	*Euglena*

3. What is the relationship between skeleton and locomotion?
4. Write briefly about skeletal muscles.
5. How muscles contract, explain the mechanism involved?
6. Write down the names of important bones in human skull.
7. Write down the names of various bones of pectoral and pelvic girdle.
8. Differentiate between endoskeleton and exoskeleton. What are various problems associated with exoskeleton and how have arthropods over come these problems?
9. Explain the modes of locomotion in various groups of invertebrates.

REPRODUCTION IN ANIMALS

7

Reproduction is the ability to produce new individuals of ones own kind. It is the means through which species tend to maintain themselves. Reproduction is one of the three basic characteristics which is essential for the living organism to survive. Food and space are the other two requirements. This is also a mechanism by which genetic variation is brought about in the species.

Types Of Reproduction

There are two main types of reproduction in animals: (i) Asexual (ii) Sexual

Asexual Reproduction

Asexual reproduction is the one in which gametes are not involved. In this mode of reproduction the parent organism simply divides into daughter organisms. This reproduction is of three types i.e., binary fission, multiple fission and budding. For example, *Amoeba* simply divides through mitotic process to give rise to two new individuals which grow and then redivide (Fig. 7.1).

Similarly, *Paramecium* also divides mitotically to give rise to two individuals. This type of asexual reproduction is also known as **binary fission**. In the case of *Amoeba,* under unfavourable conditions the animal withdraws its pseudopodia and secretes a cyst around itself. At the advent of favourable conditions the nucleus divides into a number of nuclei. A piece of cytoplasm gathers around each daughter nucleus to form a daughter amoeba. The cyst is dissolved and the daughter amoebae become free. This type of fission is known as **multiple fission**. Another type of asexual reproduction is

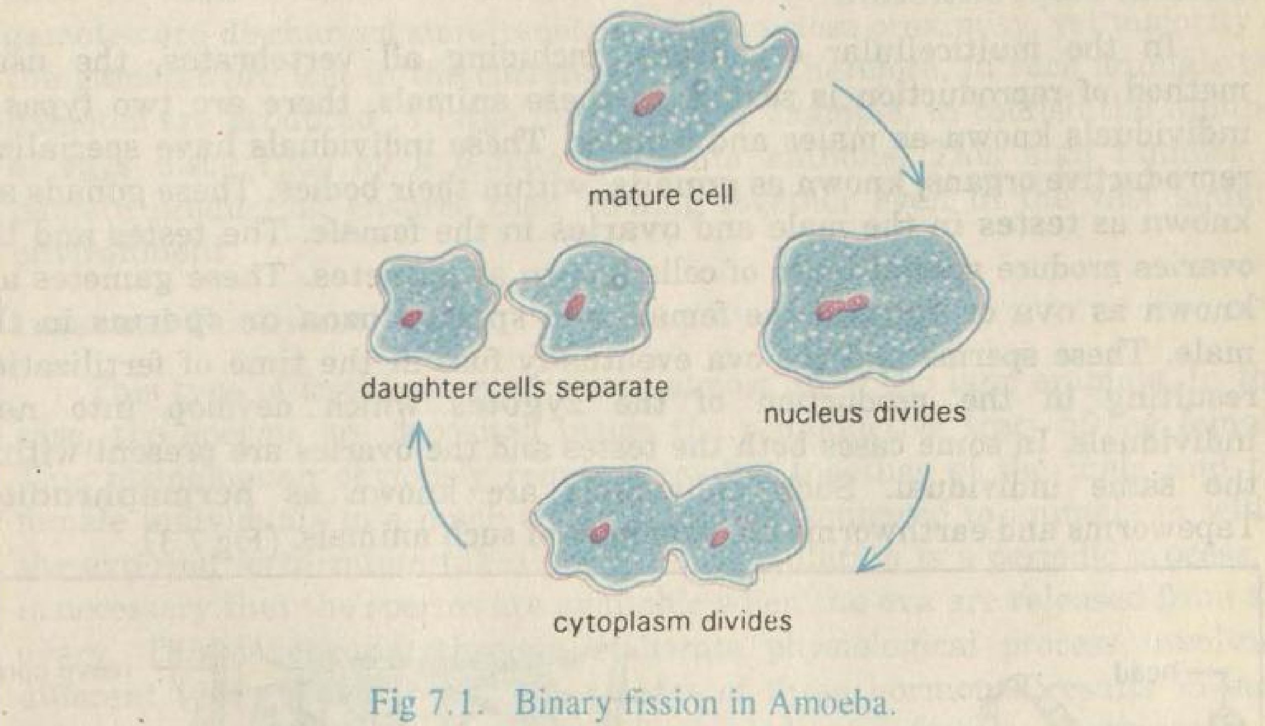

mature cell
nucleus divides
cytoplasm divides
daughter cells separate

Fig 7.1. Binary fission in Amoeba.

known as **budding**. In this process, there arises an outgrowth known as a bud on the body of the parent organism. This bud then separates and gives rise to a new individual. This type of asexual reproduction is found in some coelenterates such as *Hydra* (Fig 7.2).

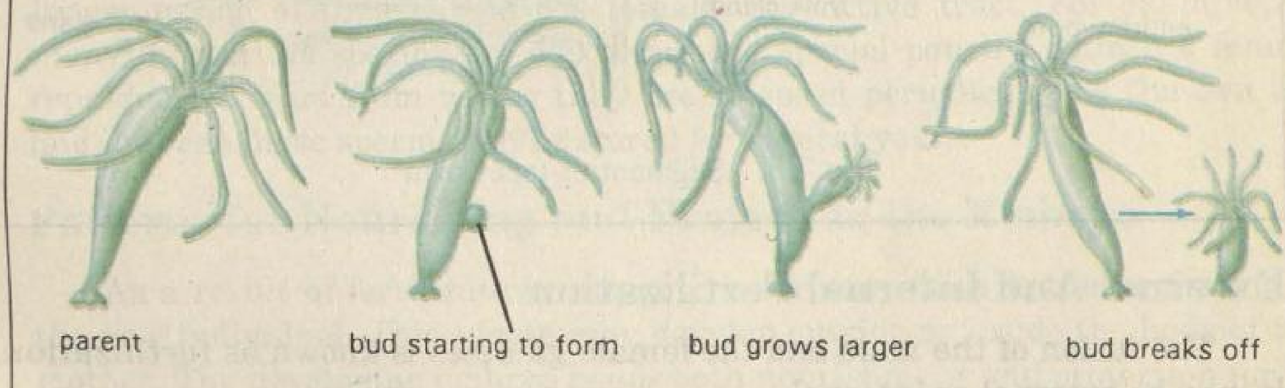

parent
bud starting to form
bud grows larger
bud breaks off

Fig 7.2. Budding in Hydra

Some Platyhelminthes, such as *Planaria,* also reproduce asexually through the division of their bodies into two halves. The lost parts are reformed to complete the animal. This process is known as **regeneration**.

Sexual Reproduction

In the multicellular organisms, including all vertebrates, the usual method of reproduction is sexual. In these animals, there are two types of individuals known as males and females. These individuals have specialized reproductive organs, known as **gonads**, within their bodies. These gonads are known as **testes** in the male and **ovaries** in the female. The testes and the ovaries produce special types of cells known as **gametes**. These gametes are known as **ova** or **eggs** in the female and **spermatozoa or sperms** in the male. These sperms and the ova eventually fuse at the time of fertilization resulting in the production of the **zygotes** which develop into new individuals. In some cases both the testes and the ovaries are present within the same individual. Such individuals are known as **hermaphrodite**. Tapeworms and earthworms are examples of such animals. (Fig 7.3).

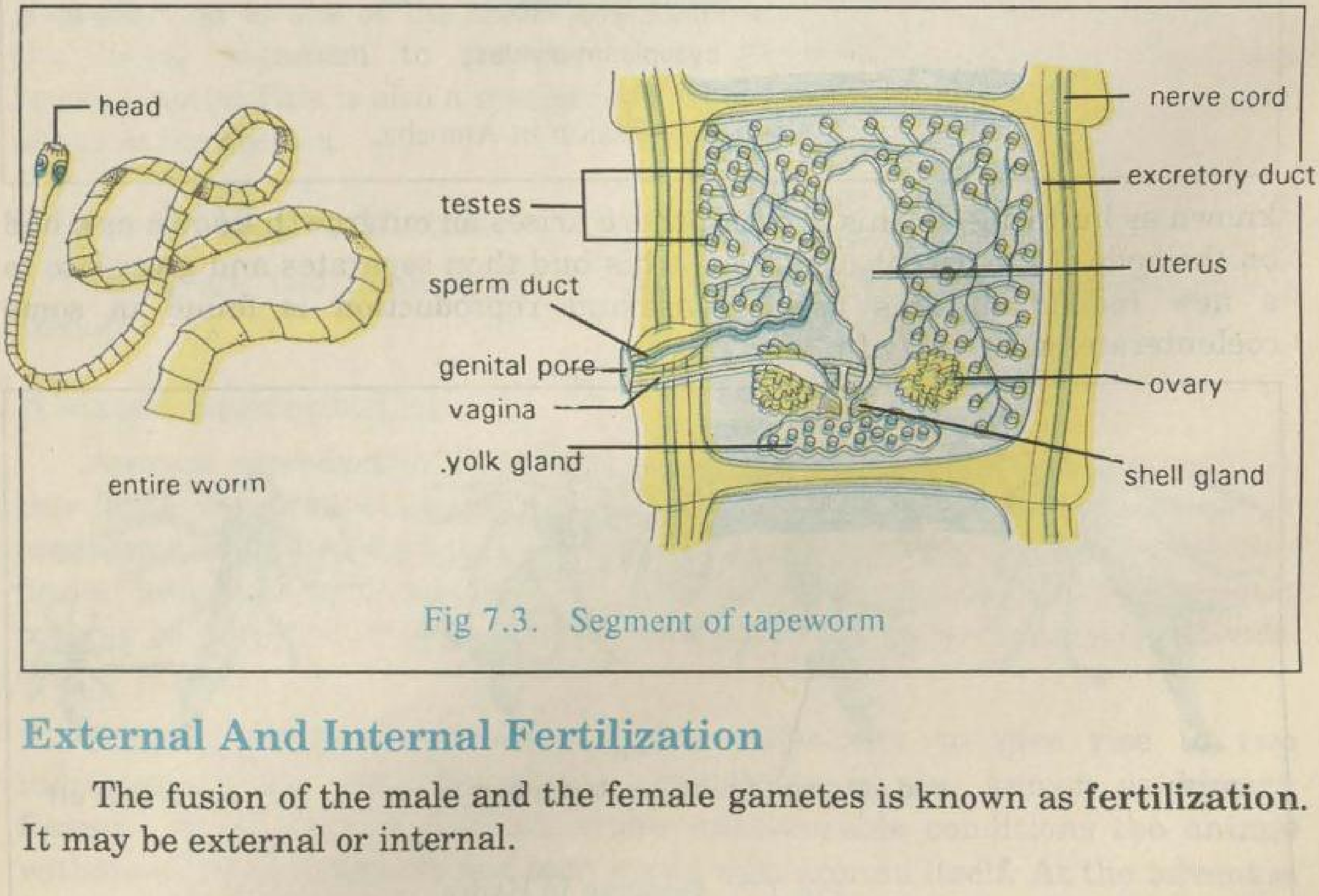


Fig 7.3. Segment of tapeworm

External And Internal Fertilization

The fusion of the male and the female gametes is known as **fertilization**. It may be external or internal.

External Fertilization

This type of fertilization is more prevalent in aquatic animals. In such animals both ova and sperms are discharged into the water where fertilization occurs. It must, however, be noted that these gametes should be discharged at the same time and in close proximity. For this, the animals have to acquire special mechanisms. Although the male and the female gametes are discharged simultaneously and in close proximity, yet majority of the gametes are lost in the currents of water. Therefore, in such animals the gametes are produced in large numbers. For example, in codfish the number of eggs discharged by a female runs into millions. This high number of gamete production ensures their coming together even in the vast aquatic environment.

Internal Fertilization

This type of fertilization occurs in almost all of the land animals. In this case, the sperms are deposited inside the reproductive tract of the female. This phenomenon obviously requires coming together of the male and the female individuals to a much closer extent as compared to animals in which the external fertilization takes place. Since ovulation is a periodic process, it is necessary that the sperms are available when the ova are released from the ovary. This is ensured through elaborate physiological process involving different types of hormones. The release of these hormones results in such behavioural patterns on the part of both male and female, that results in mating or copulation at or near the time of ovulation. The shedding of both male and female gametes at more or less the same time is also necessary, due to the fact that the period of time for which these gametes remain alive and capable of fertilization is very short. It is thus necessary that these gametes are discharged in such a way that they find each other during this short period of time. However, in some animals the sperms may survive for a much longer period of time within the female reprodctive tract. For example, in many insects the sperms are deposited in a special pouch within the female reproductive tract from where they are released periodically as the ova are laid. In bees these sperms can be stored for several years.

Patterns for Nourishing and Protecting the Embryo

As a result of fertilization, a zygote is formed which is the beginning of the new individual. This zygote may develop outside or inside the body of the mother. The developing embryo needs both nourishment and protection for its survival. The nourishment is usually provided through a large supply of food material commonly known as **yolk**, which is present within the egg. The yolk is in great quantities in those cases where the whole development of the embryo proceeds outside the body of the mother. For example, in all invertebrates and many chordates, such as amphibians, reptiles and birds, the eggs are supplied with sufficient amount of yolk which is enough to support the complete development of the embryo till such time when the egg is ready to hatch. Such animals which lay eggs and in which the whole development proceeds within the egg, are known as **oviparous** and the condition is called **oviparity**. In those cases where young ones are born, the development of the zygote proceeds within a special chamber, the **uterus**. This type of development occurs in many vertebrates, especially mammals. Such animals in which the whole development of the young ones proceeds inside the body of the mother and the mother eventually gives birth to the young ones, are known as **viviparous** while the condition is known as **viviparity**. In such cases, there is established a special kind of contact between the embryo and the mother, through which nourishment is supplied to the embryo by the mother. It is obvious that in such cases the egg does not have to be supplied with huge quantities of yolk.

Irrespective of the fact whether the development of the embryo proceeds inside or outside of the maternal body, the embryo is provided with many special structures which tend to protect it from potential hazards.

Protective Coats of Embryos

In many cases, the embryo is provided with special protective structures which are in the form of membranes or coats. Usually these coats are **amnion**

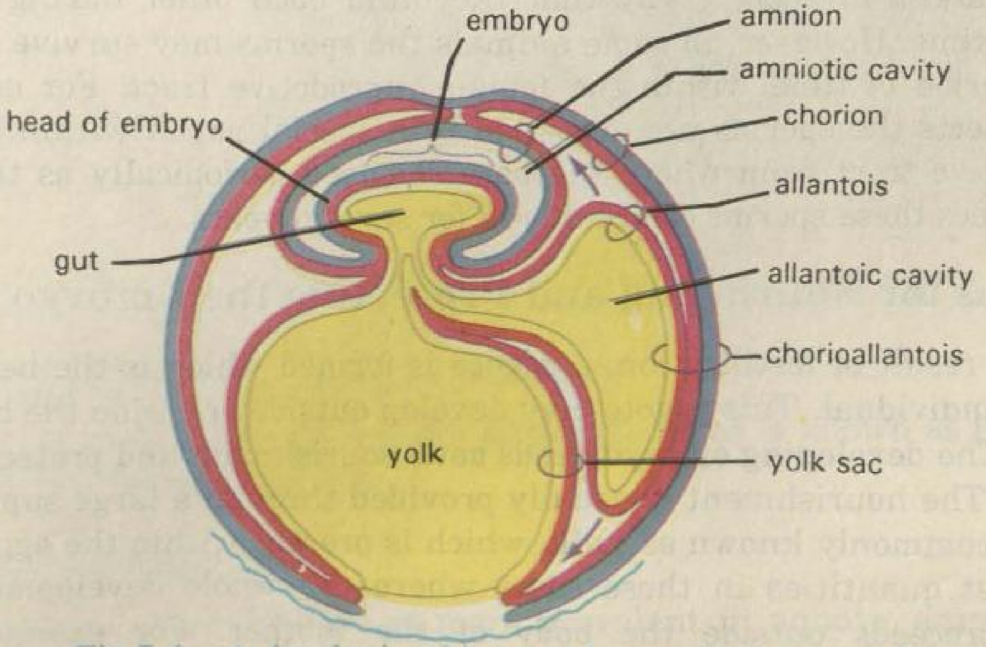


Fig 7.4. A developing bird s embryo with its protective coats.

and **chorion** (Fig.7.4). These structures appear for the first time in reptiles. These evolved basically in relation to the development of the embryo outside the maternal body in dry terrestrial conditions. In such conditions the egg is provided with a calcareous shell which is protective in its function.

Amnion is an extraembryonic membrane around the embryos of reptiles, birds and mammals. It encloses a cavity known as **amniotic cavity** which is filled with a fluid. This amniotic fluid provides a local watery medium for the developing embryo. In addition, this structure also provides protection against physical trauma. This membrane arises from the extra embryonic ectoderm and mesoderm and eventually encloses the embryo completely.

Another membrane known as **chorion** is also formed in higher vertebrates such as reptiles, birds and mammals. This membrane lies towards the extreme outside of the developing embryo, covering the whole embryonic body completely. This membrane lies very close to the egg shell or the maternal body as the case may be. In most of the reptiles and birds, this membrane comes in close contact with another structure known as **allantois**, to make a **chorio-allantoic membrane**. This chorio allantoic membrane becomes highly vascularized and acts as a respiratory organ. The allantois itself is an outgrowth from the hind gut of the embryo and its cavity acts as a reservoir for undigested food and nitrogenous waste products.

It is thus apparent that these coats not only protect the embryo but also have the additional functions of helping the embryo in respiration and storage of waste products. These structures also provide the embryo with a fluid medium to develop. This last function is extremely important because the embryos of both reptiles and birds still need water for their development, inspite of the fact that their adults have successfully adapted themselves to terrestrial mode of life.

Protection by Internal Development

The uterus of the female provides a safe and moist environment for the development of embryos in most of the animals. In some lower vertebrates also, such as sharks and in some reptiles, the development of the embryo occurs in the uterus. However, it should be noted that in these animals there is no elaborate contact between the maternal and the foetal tissues as it happens in mammals. Instead, the nutrition for the developing embryo is provided by the egg itself while the uterus serves as a safe environment for the developing embryo. In therian mammals, on the other hand, the embryo establishes a close contact with the uterine tissues through which exchange of materials takes place. This connection between the foetus and the mother is known as a **placenta**. The prototherian mammals, however, have special arrangement for embryonic development which is intermediate between reptiles on one hand and **therian** mammals on the other.

Food from the Female

The Egg Laying Mammals *(Prototheria)*

These mammals belong to a special group known as **Prototheria.** The duckbilled platypus is an example of these mammals. In these animals the egg is retained for some time within the body of the female and laid in special nests where they hatch. The newly hatched young ones are then fed on the mammary glands till they are able to look after themselves. In this way the supply of the food to the new born is ensured through the milk produced by the mammary glands of the mother. This is a very important step in the care of the young ones by mammals.

The Pouched Mammals *(Metatheria)*

This group of mammals i.e. **Metatheria,** includes opossums and kangaroos. In this group there were further steps taken in sustaining the embryos both within and outside the body of the mother. The eggs are provided with only a small amount of yolk which is barely sufficient to support the initial stages of development. These imperfectly developed embryos are expelled from the female body. These are then deposited within the pouch located on the anterior side of the belly. Here these neonates (new born) are provided with milk through the mammary glands. The pouch also provides protection and warmth to the developing young ones. These young ones stay in this pouch and are nourished for a period of time till they grow and are able to look after themselves.

The Placental Mammals *(Eutheria)*

These animals provide maximum protection and nourishment to the developing embryos. This is achieved through the formation of a placenta (Fig. 7.5).

A placenta is a structure which develops between the foetus (developing embryo) and the uterus. It develops partly from tissue of the uterus and partly from extra embryonic membrane of foetus through which an exchange of nutritive as well as waste materials takes place. In these animals the eggs are provided with only a negligible amount of yolk. The developing embryo,

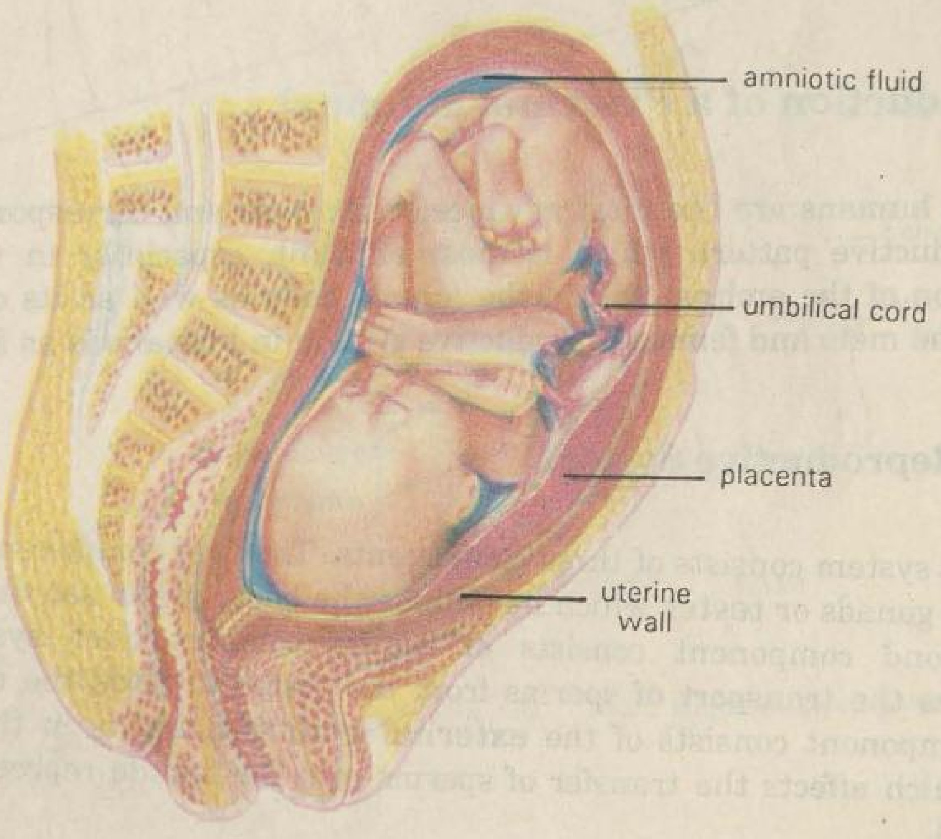


Fig 7.5. Developing mammalian foetus inside the uterus with placenta.

therefore, has to be supplied with food and nutrition at a very early stage. This is done through the establishment of the placenta. The mother thus provides all food materials necessary for the development of the embryo through the placenta. In addition, nitrogenous and other waste material of the embryo are carried back to the mother through this placenta. In this way, the mother supports the development of the embryo all the way from the beginning to the end of the embryonic period. After the young one is born, the mammary glands of the mother are available for nourishing the new born further. The young ones are supplied with milk until they are able to look after themselves. In this way, eutherian or placental mammals have evolved structures which provide maximum possible nourishment and protection to the embryos.

Reproduction of a Placental Mammal

The humans are the most advanced mammals and correspondingly show a reproductive pattern which is most efficient, especially in the sense of protection of the embryo within the female body as well as its care after its birth. The male and female reproductive system in humans is as follows.

Male Reproductive System

This system consists of three components. The first component consists of a pair of gonads or **testes** which lie outside the body, in the sac-like **scrotum.** The second component consists of highly complex duct system which facilitates the transport of sperms from the testes towards the outside. The third component consists of the **external genitalia** and is in the form of a penis which affects the transfer of sperms into the female reproductive tract (Fig. 7.6).

There are numerous convoluted tubules known as **seminiferous tubules,** within the testes (Fig. 7.7). The maturation of millions of spermatozoa takes place within these tubules at any one time. The spermatozoa are then transferred to the main duct of the male reproductive tract. This duct is known as **vas deferens,** the proximal part of which is highly convoluted and is known as the **epididymis.** The spermatozoa pass through another duct known as the **urethra** which passes through the penis. From here the spermatozoa pass on to the female reproductive tract at the time of copulation.

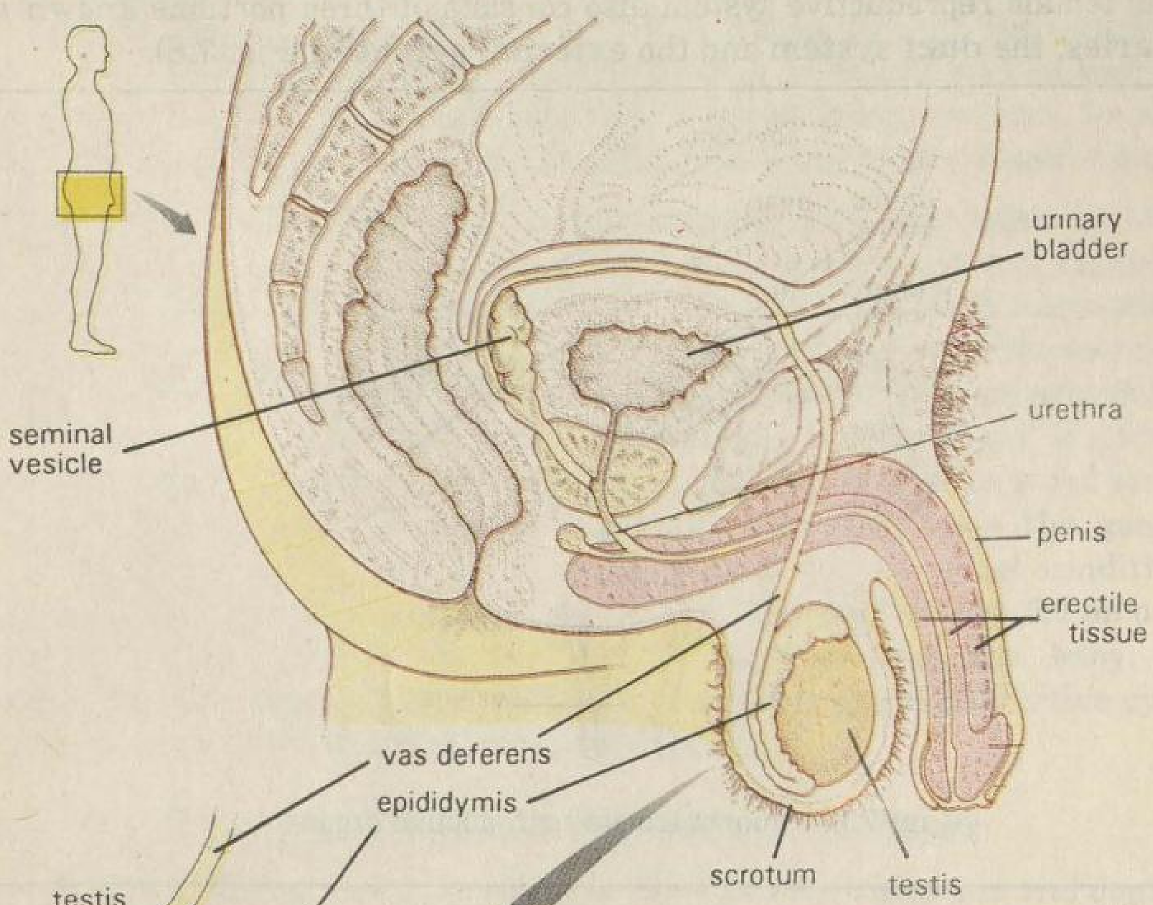

urinary bladder
seminal vesicle
urethra
penis
erectile tissue
vas deferens
epididymis
scrotum
testis

Fig 7.6. Male Reproductive System.

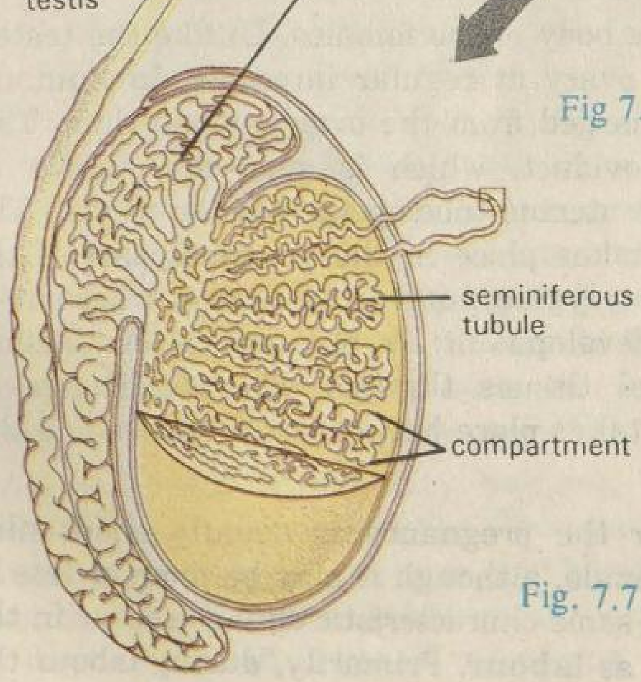

testis
seminiferous tubule
compartment

Fig. 7.7. Cross section of human testes

Female reproductive system

The female reproductive system also consists of three portions known as the ovaries, the duct system and the external genitalia (Fig. 7.8).

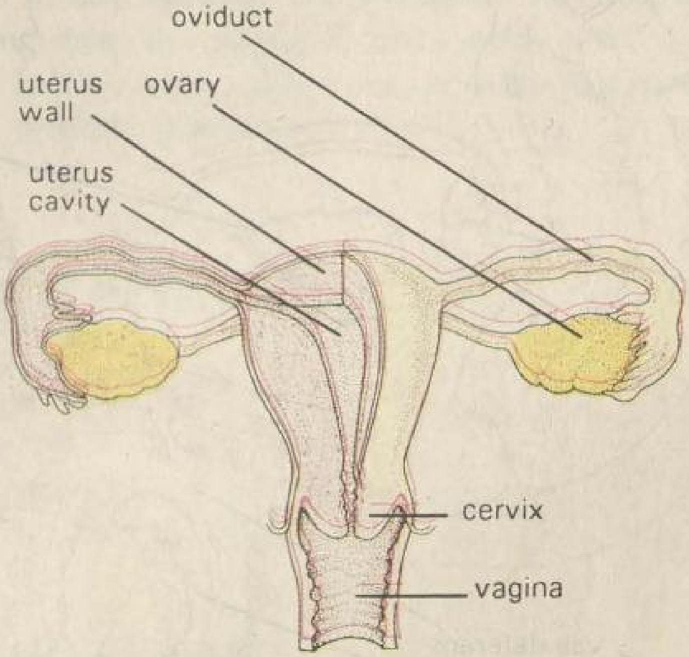


Fig. 7.8. Human female reproductive organs

A pair of **ovaries** lies within the body of the females. Unlike the testes, only a few ova mature within the ovary at regular intervals. In humans, usually only one such ovum is discharged from the ovary at one time. This ovum is then transferred to the oviduct, which is generally known as **fallopian tube** or **uterine tube**. The uterine tube opens into the uterus. The fertilization of the ovum normally takes place in the proximal part of the uterine tube. The fertilized ovum or zygote enters the uterus where it is implanted and undergoes further development. A placenta is established between the uterine and the foetal tissues through which exchange of nutritive as well as waste materials takes place between the mother and the foetus.

The total **gestation period**, or the pregnancy is usually about nine months or 280 days in the human female, although it may be more or less by a few days. At the end of this period, some characteristic changes occur in the uterus which are collectively known as **labour**. Primarily, during labour the uterine muscles undergo periodic contractions and relaxations. These movements tend to expel the baby towards the vagina which can now be called the **birth canal.** As a result of some strong and persistent contractions of the uterus, the baby is expelled through the vagina to the outside. At this time, the baby is still attached to the maternal uterus through the **umbilical cord.** As soon as the baby starts breathing, this umbilical cord is tied and eventually cut off. The contractile movements of the uterus continue for some time after birth, as a result of which the placental remains are expelled out.

The newborn baby is supplied with maternal milk soon after its birth. The mammary glands of the mother are especially prepared during the period of pregnancy under well defined hormonal control. The secretory ducts within the mammary glands branch further and undergo enormous development and start producing milk by the end of the pregnancy. The milk produced initially by the mammary glands contains a special lymph like fluid known as **colostrum** which is quite rich in antibodies. Usually, the baby is fed on the maternal milk for upto two years. However, depending upon the general health condition of the mother as well as other physiological conditions, maternal milk may not be availabel for so long. The baby is then fed on other sources of milk. As soon as the mother stops feeding the baby, her reproductive cycle begins again. However, sometimes the reproductive cycles can initiate even when the mother is breast feeding.

Hormonal Control of Female Reproductive Tract

It has been observed that in many animals such as rats, cats and dogs etc the females mate at regular intervals. This desire to mate at a specific time is known as **oestrous** or heat. This oestrous is intimately related to cyclical, structural and physiological changes which occur within the reproductive tract in the female. These changes occuring from one period of oestrous to the next constitute an oestrous cycle. It has been further observed that these cycles are related to the ovulation process, i.e. ovulation occurs during this period. It is obvious that these cycles have evolved as a means to ensure fertilization. The oestrous cycles vary in length as well as frequency. For example in laboratory rats, the oestrous cycle is of five days while in a bitch the oestrous cycle occurs every six months.

In some primates, including humans, the reproductive cycles are quite different from the oestrous cycles. This cycle, known as **menstrual cycle**, is accompanied by a periodic discharge of blood, mucous and cellular debris from the vagina. This discharge is known as **menstruation** and is the result of the break down of the soft tissues of the uterus.

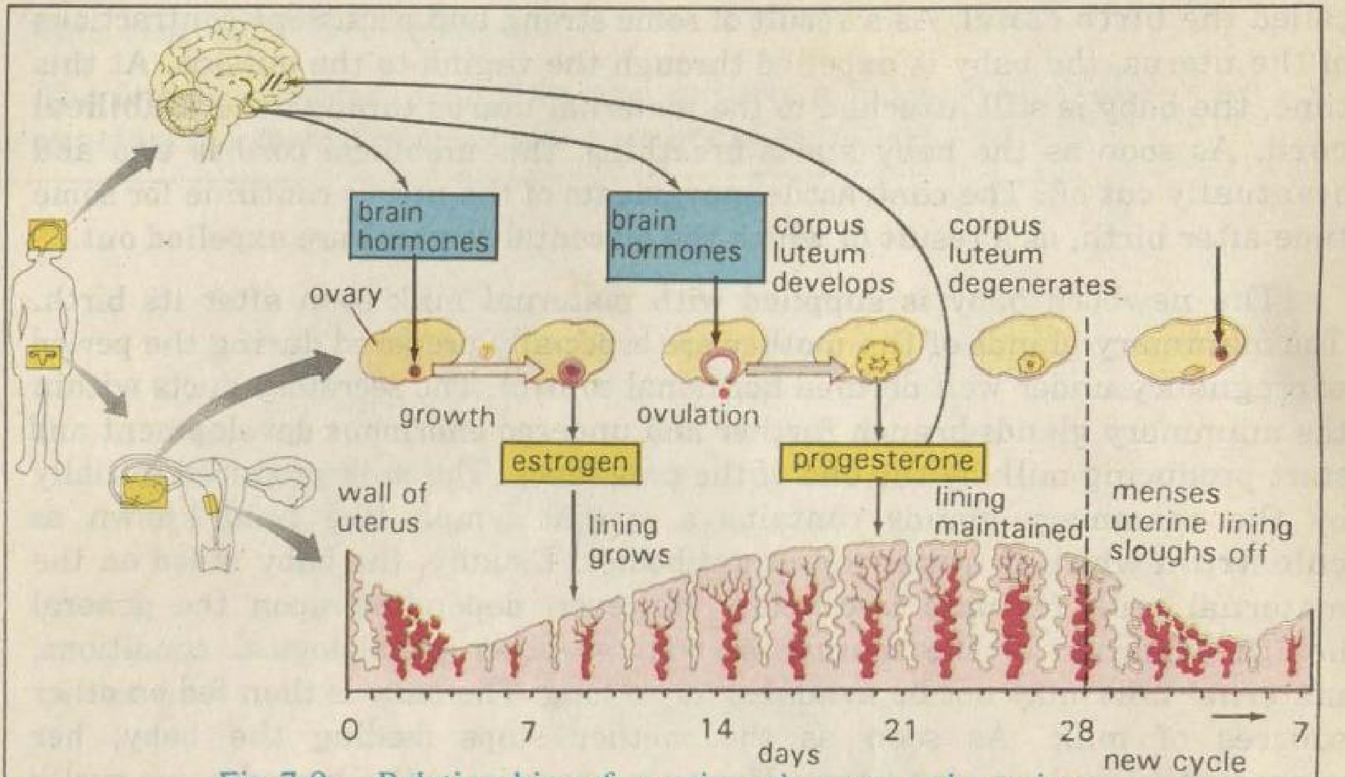

brain hormones
brain hormones
corpus luteum develops
corpus luteum degenerates
ovary
growth
ovulation
estrogen
progesterone
wall of uterus
lining grows
lining maintained
menses uterine lining sloughs off
0
7
14
21
28
7
days
new cycle

Fig 7.9. Relationship of ovarian changes and uterine mucosal changes in human during ordinary menstrual cycle and subsequent cycle in which pregnancy occurs.

The oestrous as well as menstrual cycles are under intricate hormonal control (Fig. 7.9). Two organs are mainly involved in the synthesis of these hormones. These are the ovary and the pituitary gland. In addition, placenta, once it gets established, also functions as an endocrine gland and produces hormones which play a very important role in reproduction.

The Role of the Ovary

The ovary basically consists of two types of cells the **germ cells** which give rise to the eggs, and the **follicle cells** which are somatic cells and are concerned with support and nutrition of the developing eggs (Fig. 7.10).

The follicle cells secrete the female sex hormones called **estrogens**. These estrogens primarily act on the uterus. The cells of the internal lining of the uterus (the endometrium) divide rapidly under the influence of this hormone. Some of these cells also become glandular in nature and start secreting proteinaceous secretions which are taken up by the embryo as soon as it reaches the uterus. In addition, the vascularization of the uterus also increases under the influence of the estrogens. These hormones are also known to affect the behaviour of the female. The female becomes receptive to the male and allows copulation.

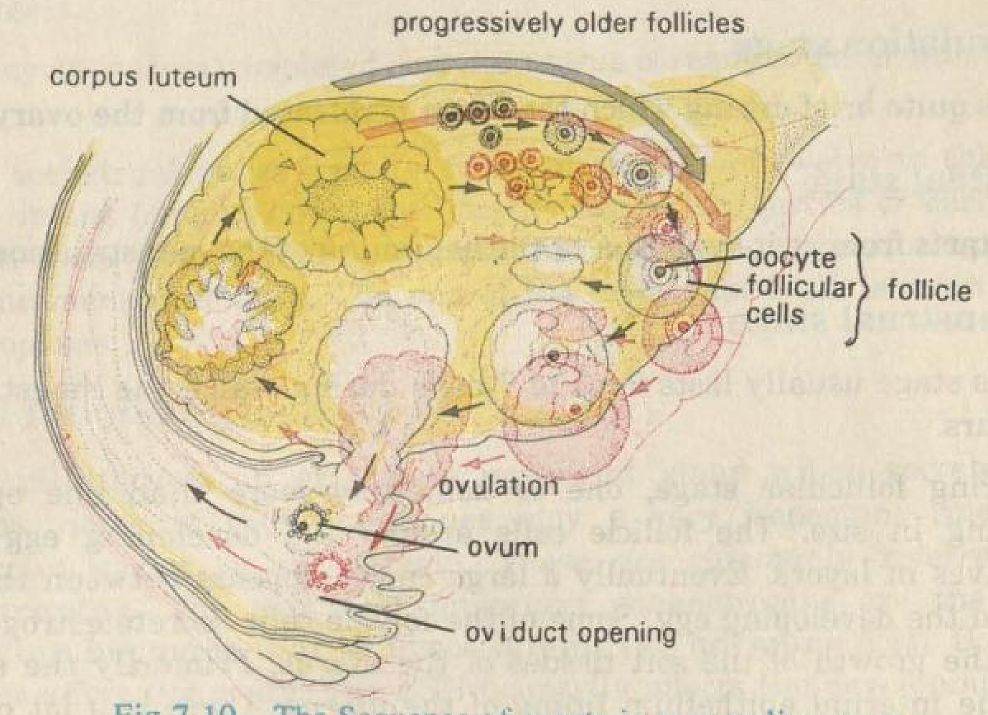


Fig 7.10. The Sequence of events in mammalian ovary.

Soon after the release of the egg from the ovary, the follicle cells which had surrounded the egg are modified to form a special structure known as **corpus luteum**. This structure is yellowish in colour and its cells become glandular and start secreting a hormone known as **progesterone**. This hormone is also important for the preparation of the uterus. It affects both the myometrium (muscles of the uterine wall) and endometrium of the uterus (Fig. 7.8), so as to fully prepare the uterus for the implantation of the zygote. It can be exerimentally confirmed that these hormones of the ovary are essential for preparing the uterus for implantation. If the ovary is removed from an immature mouse, its uterus will not undergo the preparatory structural and functional changes mentioned above.

Changes in Ovary and Uterus during Menstrual Cycle

The humans menstrual cycle generally repeats every 28 days although there is considerable variation in different individuals or even within the same individual at different times. The ovulation occurs somewhere around the middle of the cycle. For descriptive purposes the menstrual cycle can be divided into four stages.

1. Follicular stage

The stage starts from the end of the previous menstrual flow and ends at ovulation

2. Ovulation stage

It is quite brief during which the ovum is released from the ovary.

3. Luteal stage

It starts from post-ovulation to the beginning of the menstruation

4. Menstrual stage

This stage usually lasts for 3 to 7 days during which the menstrual flow occurs.

During follicular stage, one or sometime more than one egg starts increasing in size. The follicle cells around the developing egg arrange themselves in layers. Eventually a large cavity appears between the follicle cells and the developing egg. Some of the follicle cells secrete estrogen which affects the growth of the soft tissues of the uterus. Primarily the estrogens affect the internal epithelium lining of the uterus. There is a lot of mitotic activity in this epithelium. In addition, the blood supply of the uterus is also increased under the influence of estrogens as a result of which the uterine tissue becomes spongy in nature.

As the developing egg reaches a certain stage of development, it is shed outside the ovary, that is, ovulation occurs. The egg then finds its way to the fallopian tube. This process of ovulation is under intricate hormonal control and represents ovulation stage of the menstrual cycle.

Following ovulation, the follicle cells, which had surrounded the developing egg, become modified into glandular cells and start secreting another hormone known as **progesterone**. These special glandular cells constitute **corpus luteum**. The progesterone, which is secreted by corpus luteum prepares the uterus for imminent fertilization and implantation of the zygote. The uterine epithelium becomes folded, the vascularity increases further, as a result of which the whole endometrium part of the uterus becomes soft and spongy as well as highly vascularized (Fig. 7.9).

If fertilization does not occur, the corpus luteum starts degenerating. As a result of this the progesterone secretion diminishes, so much so that the thickened spongy part of the uterus suffers a breakdown. This brings about the onset of menstruation stage of the menstrual cycle. During this phase the broken down soft tissues of the uterus are discharged alongwith considerable amount of blood which is released as a result of the breakdown of the uterine blood vessels.

The cycle is thus completed and the uterus is ready to enter into the next cycle.

The menstrual cycles usually starts at the age of twelve to thirteen or fourteen in the females and cease by the age of late forties or early fifties. However, there is considerable variation in age both for beginning and the end of the menstrual cycle. The end of the menstrual cycle is referred to as the menopause.

Role of Pituitary Gland

The pituitary is an extremely important gland which secretes many hormones. Some of these hormones play a very important role in the reproductive cycles in the female. These are commonly referred to as **gonadotropins**. The two most important gonadotropins are the **follicle stimulating hormone** (FSH) and the **luteinizing hormone** (LH). Both these hormones affect the ovary. The FSH primarily affects the developing oocytes within the ovary. These follicles grow in size to become mature follicles commonly called the **Graafian follicle**. The LH becomes effective at this stage and stimulates the release of the egg, a process known as the ovulation. It has also been seen that follicle cells surrounding the developing oocytes secrete estrogen. Thus, both FSH and LH also bring about the secretion of estrogen in an indirect way. As has been mentioned before, estrogen is very important in bringing about structural and functional changes in the uterus.

A third important pituitary hormone which should be considered at this stage is **luteotropic hormone** (LTH). It is also called as **prolactin** because it stimulates the development and the secretion of milk in the mammary glands. This hormone also affects the corpus luteum which then secretes progesterone (Fig. 7.11).

The importance of pituitary gland in the functioning of the ovaries and the reproductive cycles can be appreciated through simple experimental means. If the pituitary gland is removed in a young female animal, her reproduction is completely interfered with. The ovaries do not develop and there is no sign of reproductive cycles. Since ovarian hormones are not formed, the uterus also does not undergo the typical structural and functional changes.

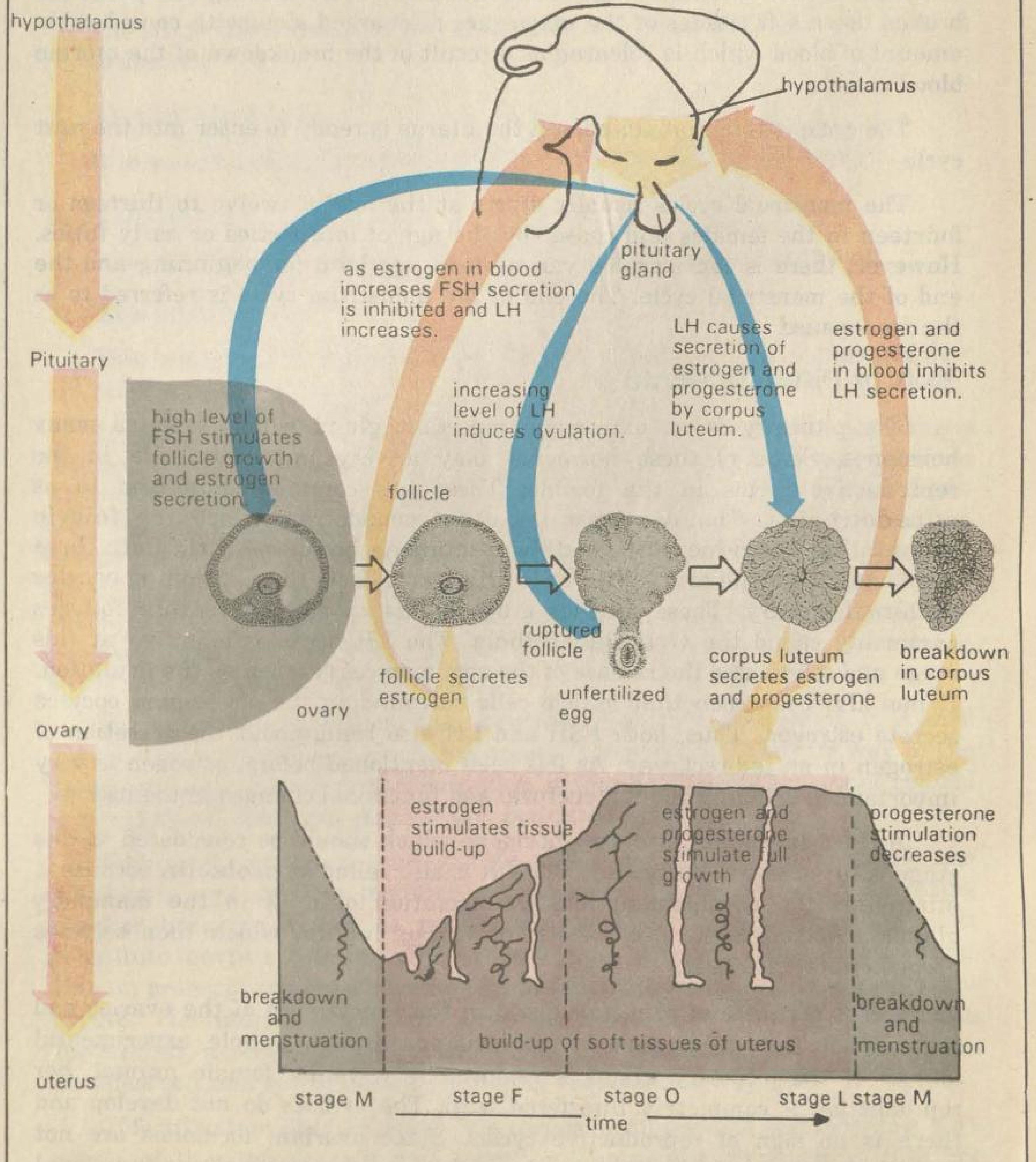

hypothalamus
hypothalamus
pituitary gland
as estrogen in blood increases FSH secretion is inhibited and LH increases.
LH causes secretion of estrogen and progesterone by corpus luteum.
estrogen and progesterone in blood inhibits LH secretion.
Pituitary
increasing level of LH induces ovulation.
high level of FSH stimulates follicle growth and estrogen secretion
follicle
ruptured follicle
unfertilized egg
corpus luteum secretes estrogen and progesterone
breakdown in corpus luteum
follicle secretes estrogen
ovary
ovary
estrogen stimulates tissue build-up
estrogen and progesterone stimulate full growth
progesterone stimulation decreases
breakdown and menstruation
build-up of soft tissues of uterus
breakdown and menstruation
uterus
stage M
stage F
stage O
stage L
stage M
time

Fig 7.11. Hormonal control of Pituitary during female reproductive cycle.

Hormonal Control by the Placenta

As has been mentioned above, the initial structural and functional preparation of the uterus to receive the developing embryo is carried out under the influence of ovarian estrogen and progesterone. Soon after the developing embryo gets embedded into uterine wall, a placenta is established. It has been observed that some cells of placenta become specialized and start secreting hormones which are quite similar in action to the pituitary hormones. The chorion part of the placenta secretes a hormone commonly called **Chorionic gonadotropin**. It acts somewhat like LH but also has LTH activity. This hormone thus stimulates and maintains the corpus luteum within the ovary to keep on secreting progesterone for a considerable period of time. The placenta eventually produces progesterone by itself and at this stage the ovarian progesterone can be dispensed with. In addition to progesterone the placenta also secretes estrogen.

It is interesting to note that in some mammals the presence of ovaries is essential for the continuation of pregnancy. For example if the ovaries of female rats, mice or rabbits are removed at any stage of pregnancy, the embryo does not survive and is aborted. In some other mammals however, such as horses, monkeys and in humans, the ovaries can be removed even during relatively early stages of pregnancy without any harm to the developing embryo. It is obvious that in such cases the placenta is able to produce all those hormones which are necessary for the maintenance of the pregnant uterus. In those cases, where removal of the ovary results in cessation of pregnancy, it is obvious that the placenta is not able to produce enough quantities of the hormones which can take over the functions of the ovarian hormones.

After the birth of young one, the whole hormonal set up involving the ovary, uterus and placenta ceases to function as such and thus is replaced by the regular reproductive cycles.

QUESTIONS

1. What is reproduction? What are its two principal types and how do these types differ from each other?
2. What is fertilization? What are the main differences between external and internal fertilization?
3. Give an account of the coats or membranes which protect the embryos during development.

4. Describe how Prototheria and Metatheria provide protection and nourishment to their young ones.
5. Describe the male or female reproductive organs in humans.
6. What are estrogens? Where are they synthesized and what are their effects?
7. Describe the various stages encountered during the menstrual cycle in a human female, giving salient features of each stage.
8. Which hormones of the pituitary gland are involved in the female reproductive system and what are their main effects?
9. What is a placenta? What kinds of hormones does a human placenta produce?

DEVELOPMENT IN ANIMALS

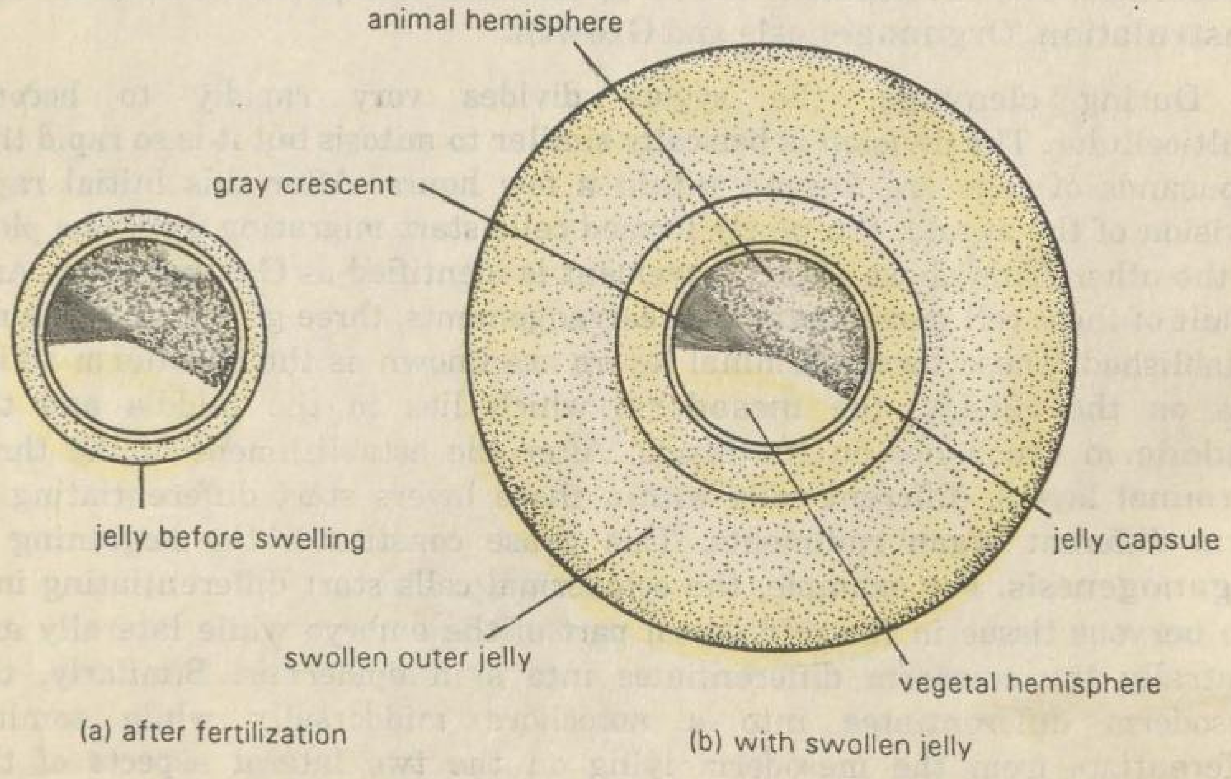
8

As soon as the ovum is fertilized to form a zygote, it starts undergoing a highly complicated process of development as a result of which it eventually acquires features which resemble with those of its parents. At this stage, the new individual comes out of the egg membrane or the maternal body as the case may be. The branch of biology which deals with the study of the development of the zygote till it is hatched or born is known as **Embryology.** Although the details of the developmental processes may differ in various animals, there is a general pattern of development which is common to all vertebrates. The development can be divided into four processes as **Cleavage, Gastrulation, Organogenesis** and **Growth.**

During **cleavage**, the zygote divides very rapidly to become multicellular. The division is basically similar to mitosis but it is so rapid that thousands of cells are formed within a few hours. After this initial rapid division of the zygote, the newly formed cells start migrating from one place to the other. This phase of cell movement is identified as **Gastrulation.** As a result of these cell movements and rearrangements, three germinal layers are established. These three germinal layers are known as the **ectoderm** which lies on the outside, the **mesoderm** which lies in the middle and the **endoderm** which lies on the inside. After the establishment of the three germinal layers, different cells within these layers start differentiating to form different organ rudiments. This phase constitutes the beginning of **organogenesis.** For example, the ectodermal cells start differentiating into the nervous tissue in the mid dorsal part of the embryo while laterally and ventrally the ectoderm differentiates into skin epidermis. Similarly, the mesoderm differentiates into a notochord middorsally while somites differentiate from the mesoderm lying on the two lateral aspects of the notocord; still laterally and ventrally the mesoderm differentiates into side plate. The endoderm gives rise to the main digestive tube or the gut which eventually differentiates further into foregut, midgut and hindgut. This phase of organogenesis is followed by a long phase of **growth** and differentiation. During this phase, all these basic organ rudiments increase in size and also undergo many physiological changes as a result of which embryo comes to acquire fully functional organs. As this happens, the embryo becomes capable of independent existence and thus is ready to start life on its own. It, therefore, either hatches i.e. comes out of the egg as in birds and reptiles, or is born as in the case of therian mammals. Let us now study these processes of development in a frog, which will help us to understand better these devlopmental processes.

Development of Frog

The female frog lays eggs in water during rainy season. As soon as the eggs are passed through the cloaca to the outside, they are fertilized by the sperm which are discharged by the male which mounts the female at this time. The fertilization, therefore, is external in this animal.



(a) after fertilization (b) with swollen jelly

Fig 8.1. Fertilized egg of the Frog.

The egg of a frog is quite large. It is darkly pigmented towards one pole which is known as the **animal pole.** The other pole of the egg is yellowish in colour and is known as the **vegetal pole.** The egg is supplied with a considerable amount of yolk which is concentrated towards the vegetal pole and gives yellow colour to this pole. The nucleus of the zygote lies more towards the animal pole within the cytoplasm which is relatively free of yolk. (Fig 8.1).

Soon after fertilization, the zygote starts undergoing cleavage. The first cleavage is always vertical passing through the animal and the vagetal poles. This cleavage thus bisects the zygote into two equal cells which are known as **blastomeres.** The second cleavage is also vertical but at right angle to the first one, resulting in the formation of four blastomeres. The third cleavage is horizontal but shifted towards the animal pole resulting into the formation of four upper smaller blastomeres known as the **micromeres.** The four lower blastomeres are larger and are known as the **macromeres** (Fig. 8.2). As the cleavage continues there appears a small cavity within the dividing blastomeres. This cavity, known as **blastocoele,** is located more towards the animal pole (Fig. 8.2a)

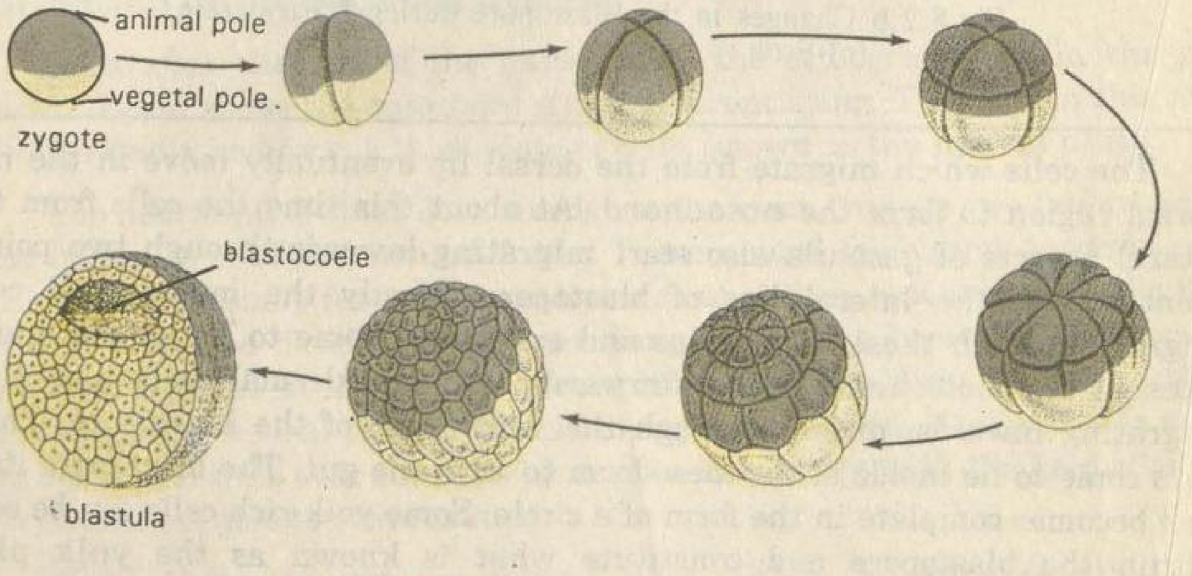


Fig 8.2 a Cleavage and blastulation in Frog

The embryo at this stage is known as **blastula.** This stage is transitory between cleavage and gastrulation.

The initiation of **gastrulation** can be identified by the appearance of a dent or cleft towards one side, at the junction of micromeres and macromeres. This dent is actually formed as a result of migration of cells at this point. This dent therefore marks the dorsal lip of the blastopore. As more and more cells migrate inwords at this point, the dorsal lip of blastopore becomes more prominent (Fig. 8.2b).

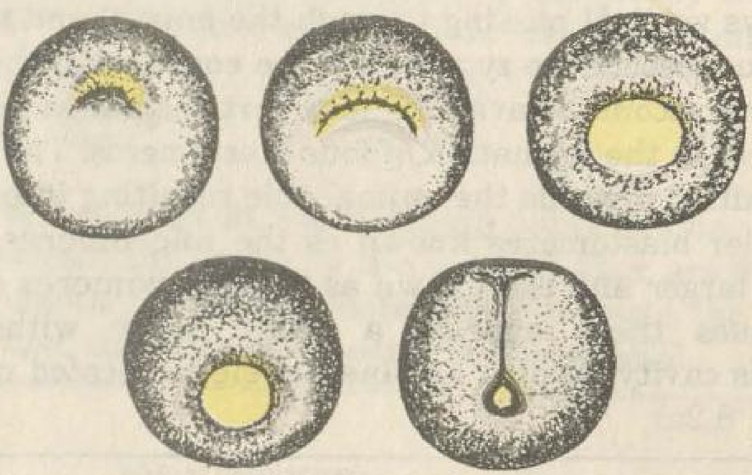


Fig 8.2.b Changes in the Blastopore during Gastrulation of Frog

The cells which migrate from the dorsal lip eventually move in the mid dorsal region to form the **notochord.** At about this time the cells from the lateral aspects of gastrula also start migrating inwards through two points identified as the lateral lips of blastopore. Mostly the mesodermal cells migrate through these lateral lips and eventually come to lie on the lateral sides of the notochord. Soon afterwards, the endodermal cells also start migrating inwards, mostly through the ventral lip of the blastopore. These cells come to lie inside of the mesoderm to form the gut. The blastopore itself now becomes complete in the form of a circle. Some yolk-rich cells can be seen within the blastopore and constitute what is known as the **yolk plug** (Fig. 8.2c). With the establishment of the three germinal layers the gastrulation now comes to an end. By this time, the basic organ rudimentation is completed.

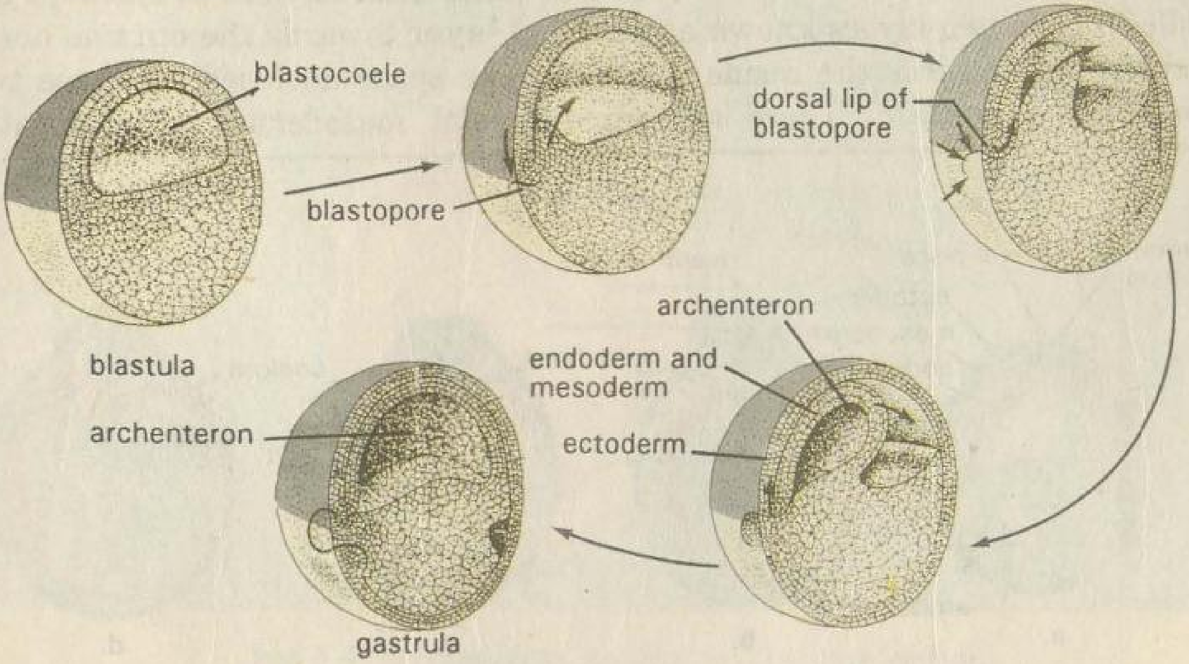


Fig 8.2 c. Stages of development of a frog embryo.

Formation of the Nervous System

Soon after the end of the gastrulation the ectoderm lying in the mid dorsal region above the notochord starts differentiating. The cells in this area divide rapidly and form a thick plate of cells, known as the **neural plate.**

The neural plate sinks downwards. At the same time its two lateral edges rise in the form of two **neural folds.** These neural folds grow towards each other and eventually fuse mid dorsally so as to enclose a neural tube (Fig.8.6). At this stage the developing embryo elongates and is known as a **neurula.** The anterior part of the neural tube soon enlarges to form the brain while posteriorly the neural tube gives rise to the **spinal cord.** At about this stage the epidermal cells over the embryo acquire small cilia with the help of which the neurula is able to swim around.

While these changes are taking place within the ectoderm, the basic organ rudiments derived from mesoderm also undergo progressive changes. The notochordal cells acquire a special kind of **gelatinous protein** which makes them turgid or stiff. Thus, the notochord acts as a **"back bone"** of the embryo. The somatic mesoderm lying on the two lateral sides of the notochord also undergoes proliferation and eventually gives rise to the vertebral column, the muscles of the back and dermis of the skin. The vertebral column eventually replaces the notochord. The side plate mesoderm soon splits in the middle to form two layers known as **parietal layer** towards the outside and a visceral layer towards the inside (Fig. 8.4). The space enclosed by these two layers is the **coelom.** There are some special mesodermal cells located between the somatic and side plate mesoderm. These cells eventually give rise to the urinary system and are thus called as **nephrotome.**

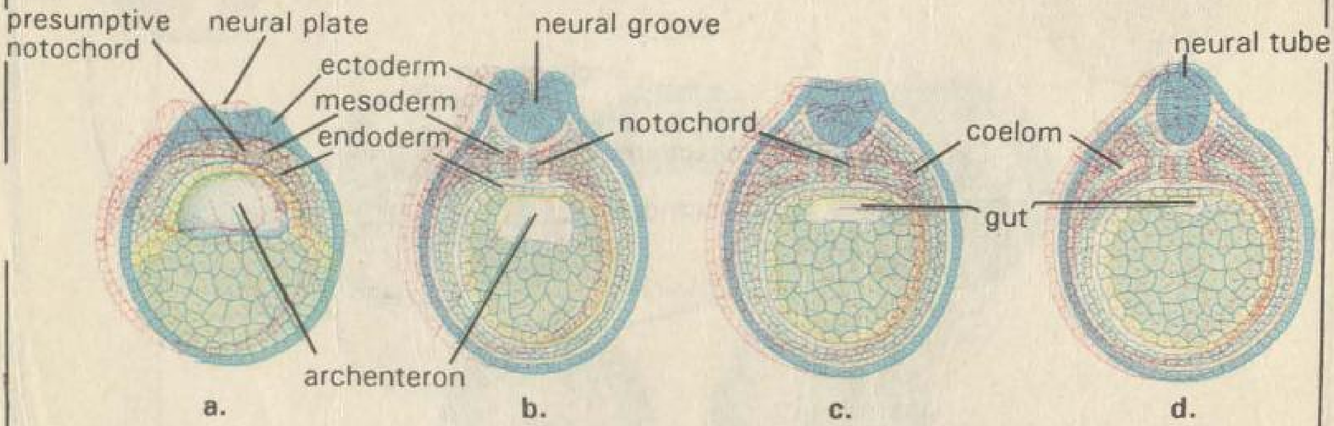


Fig 8.3. The formation of the neural tube in a frog. Dorsal parts of four developmental stages are shown in cross-section.

The endodermal cells also divide and eventually give rise to the alimentary canal along with associated glands such as liver and pancreas. The developing gut is demarcated into a fore-gut, a mid-gut and a hind-gut. Further differentiation of these parts results in the formation of buccal cavity, oesophagus, stomach, small and large intestines and the cloaca. The liver and the pancreas arise as outgrowths from the fore-gut. The respiratory system in the form of trachea and lungs also arises from the endoderm at about this level.

Once these organs are formed, we find the typical vertebrate organ system is established. This organ system is quite typical of all vertebrates and is universally present within their embryos.

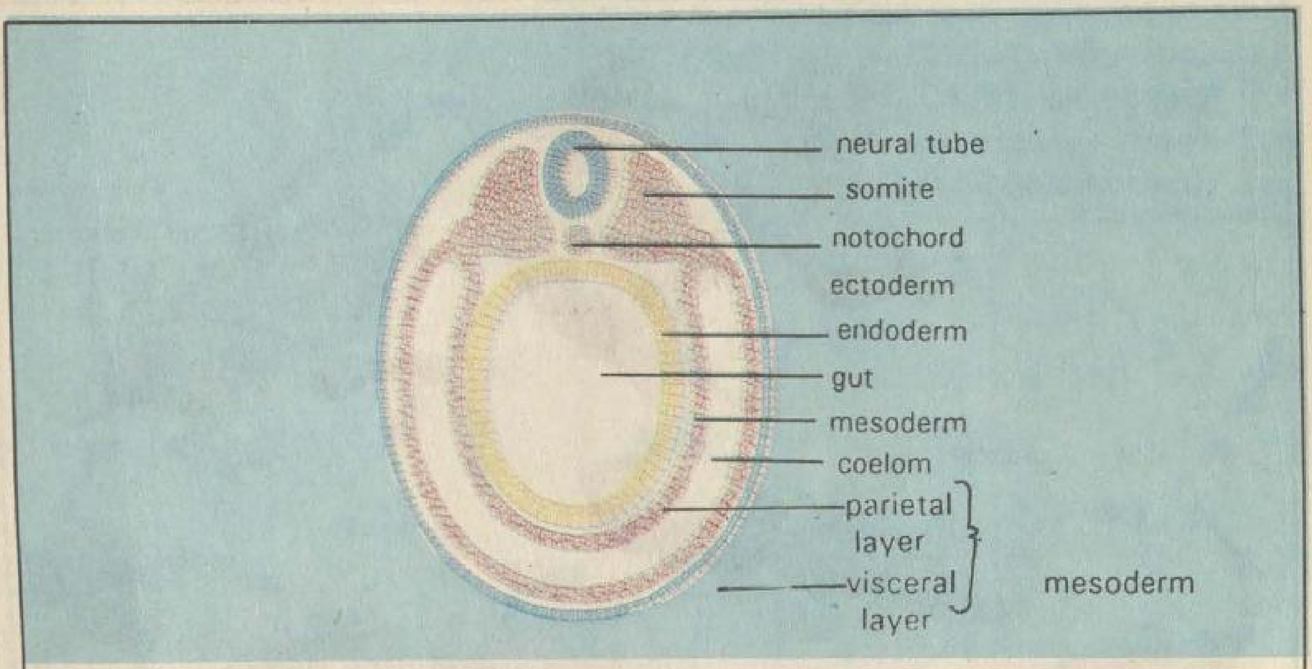


Fig 8.4. Transverse section of the frog embryo.

Metamorphosis

When all basic organs become established and start functioning, the embryo is now capable of independent existence. It is at this stage that the embryo comes out of the egg membrane as **larva.** This larva, which is known as a **tadpole,** has a well developed tail with the help of which it swims around (Fig. 8.5)

Larval stage lasts for a few days after which there are series of major structural and functional changes within the larva. As a result of these changes, the larva becomes a small froglet. This whole process by which the larva changes into an adult is known as **metamorphosis.** Basically three types of changes occur during this process. These can be categorized as **retrogressive, progressive** and **organizational** changes. The retrogressive changes are those in which the existing structures are lost. For example, the whole tail of the tadpole and also its gills are lost. Progressive changes involve the appearance of some new structures. For example limbs develop during metamorphosis. Organizational changes include modification in intestine which becomes much shorter, and the skin which much becomes thicker and acquires skin glands.

ectoderm also remained alive and healthy but failed to develop into nerve tube.

Experiment 2.

Spemann took an early gastrula and removed the mesoderm from the roof of the archenteron. The embryo healed and lived but its ectoderm failed to develop into the nerve tube.

Experiment 3.

In the final experiment he used two embryos in the early gastrula stage. From one of the early gastrulae he removed a piece of mesoderm from the dorsal lip of the blastopore. From the second embryo he removed a similar sized piece from the mesodermal area 180° from the dorsal lip. In its place he put the piece of dorsal lip from the first embryo. The transplanted mesoderm formed a blastopore and moved inside the embryo. The embryo healed and developed but unlike the normal embryo it had two nervous systems. One nervous system was at normal position while the second nervous system was in response to the transplanted dorsal lip of blastopore. This embryo developed as siamese twin with two heads and one trunk.

In this way Spemann finally proved that it is the mesoderm which influences ectoderm to differentiate into nerve tube.

Aging

Aging or getting old is a phenomenon which we observe all around us. Soon after a human is born, it gradually starts growing in size and strength. It reaches the age of puberty and then becomes an adult. However, after this stage there set in some physiological changes within our bodies which can be identified as regressive or degenerative leading to general weakness and decrease in our body's ability to cope with stress. These negative changes in our body are identified as the process of aging. As these negative changes continue a stage is reached when we become vulnerable to all kinds of stresses including radiation and diseases. Eventually our body systems completely cease functioning as a result of which death occurs.

When we study aging at cellular and molecular level, we find that this process is also programmed, just like all other developmental processes within the cell. Generally, all types of cells in our body are programmed to undergo mitosis for a certain number of times. This period is characterized by an overall growth of our body. After the cells undergo a certain number of cell divisions, they stop dividing and become differentiated. This phase of differentiation is characterized by intense synthetic activity of specialized proteins, both structural as well as enzymatic. Due to the presence of these proteins the cells become physiologically active and perform their functions most efficiently. Overall this phase of our life is identified as youth. At this stage, in addition to showing a height of metabolic activity our body tissues and organs also show maximum resistance to negative environmental stresses. As mentioned above, viruses, bacteria and radiation are the main environment stresses. After passing through this phase of maximum metabolic activity and resistance, the cells within our body gradually start deteriorating. Their synthetic activity slows down and eventually comes to a standstill. Their resistance to negative environmental factors starts decreasing, as a result of which these factors start taking their toll. In addition, changes within the genome of the cells further deteriorate the functioning of the cells and finally of the individual. This comprises the process of aging.

Regeneration

You must have noticed that the tail of a common wall lizard can break very easily and soon afterwards a new tail is formed which replaces the

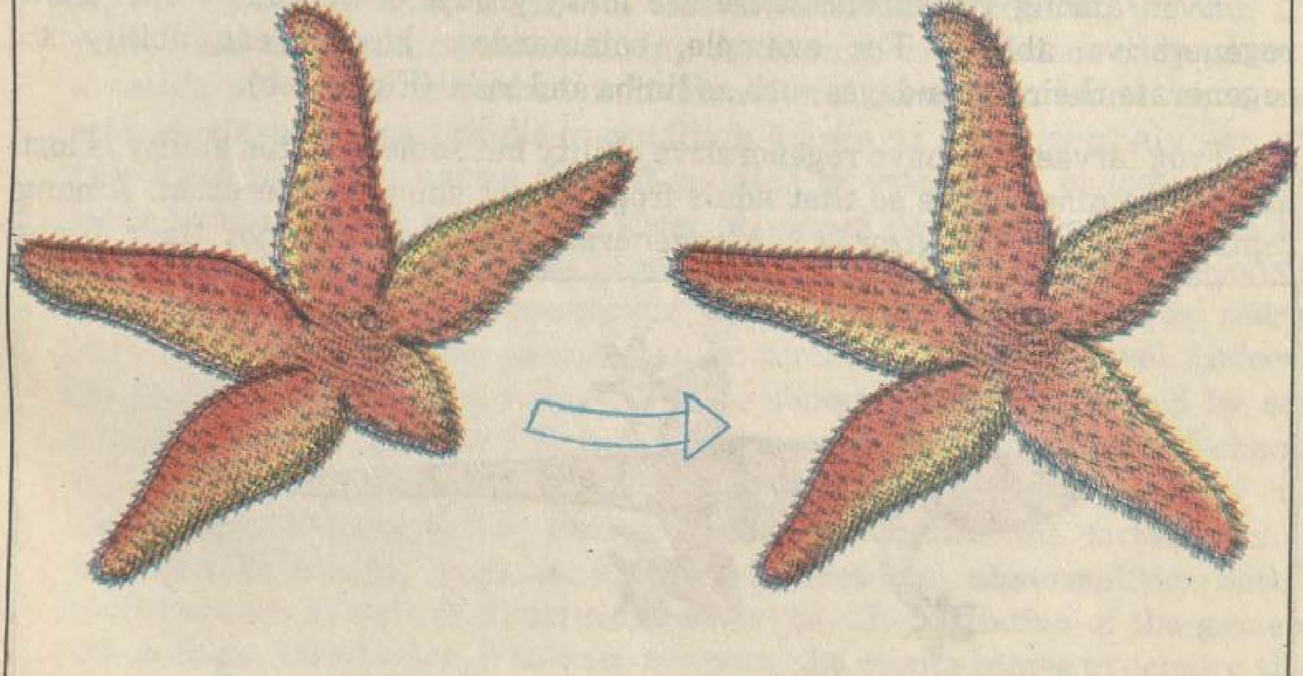


Fig. 8.7. a. Regeneration of a missing arm in the star fish.

missing part. This ability to form a part of the body which had been removed, is known as **regeneration.** This property of regeneration is quite widespread in both plant and animal kingdoms. As far as animals are concerned, many of the invertebrates possess this ability. For example, if the head of an earthworm is removed, a new head regenerates. Similarly, if a lobster losses its pincer claw, a new claw regenerates in its place. A starfish can regenerate its arm if it is accidently or deliberately removed (Fig. 8. 7 a).

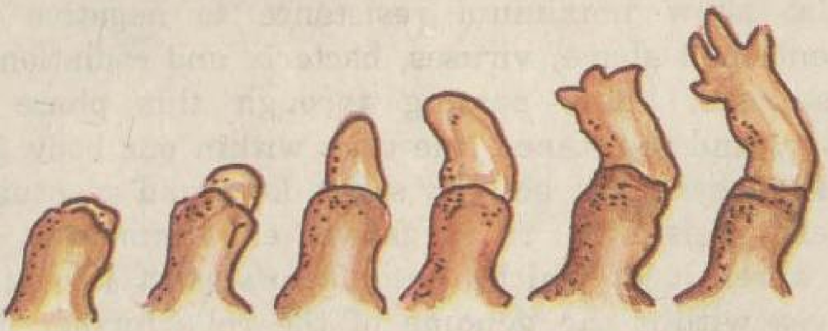


Fig. 8.7. b. Consecutive stages of forelimb regeneration in salamander.

Even among vertebrates there are many groups of animals which show regenerative ability. For example, salamanders have great ability to regenerate their appendages such as limbs and tails (Fig 8. 7 .b).

Frog larvae also have regenerative ability but somehow this ability is lost during metamorphosis so that adult frogs do not show regeneration. Among reptiles most of the lizards can regenerate their tail but not their limbs

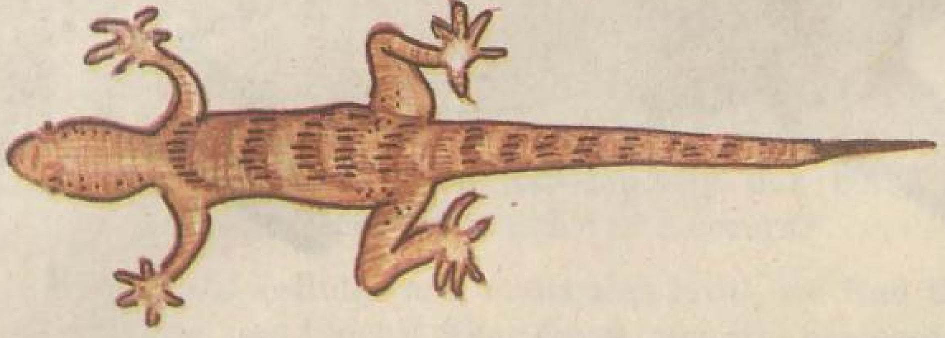


Fig. 8.7. c. Regeneration of the tail in lizard.

(Fig. 8.7 .c).

Among birds and mammals, regenerative ability is quite poor. In humans this ability is restricted only to the regeneration of part of our skin after minor cuts and bruises.

The most interesting aspect of regeneration is that the formation and development of the missing organs occurs in the adult animal by the same processes by which this organ had developed during embryonic stages. In other words, the same embryological processes are repeated in adult animals. It seems that there may be a retention of some undifferentiated embryonic cells within the adult body which may be responsible for the formation of the missing part. This possibility has been verified to exist in many invertebrate animals. Among vertebrates, the presence of such embryonic cells has not been confirmed as yet. Instead, the cells present locally at the site of amputation or injury have been seen to undergo a process of dedifferentiation. As a result these cells acquire embryonic nature. These cells start dividing rapidly and eventually dedifferentiate into various parts of the missing organ.

Abnormal Development

As you may have understood by now, embryonic development of an animal is a very intricate process in which various events follow each other in a precise manner. We have also seen that these processes are under strict control of the genome. Inspite of this predetermined control, we find that quite often abnormalities arise during the formation of various body parts, as a result of which malformed individuals are born. You must have seen individuals with small skulls (a condition known as **microcephaly**), or with hare-lip (a condition known as **cleft palate**), or with more, or less, than five digits in their hands or feet. All these abnormal developments indicate that there must have occurred some lapses in the control mechanisms responsible for the developments of these organs. Obviously, one of the principal reasons for these abnormal developments can be traced to the gene level. Indeed it has been discovered that many of these abnormalities are caused by some mutations at the gene level or some structural as well as numerical changes at the chromosomal level. The gene mutation within the zygote may have occurred spontaneously or through some environmental factor such as radiation. Similarly, there may occur chromosomal abnormalities both in their number as well as structure, during the differentiation of the gametes. When these gametes unite to form a zygote, the zygote comes to acquire these chromosomal abnormalities, thus leading to abnormal development. Another major reason for abnormal development is related to the functioning of the glands of both the mother or of the foetus itself. For example, it has been observed that if the pituitary gland of the mother or of the foetus does not function properly, there arise many structural and functional abnormalities within the foetus. The main defects are **gigantism** (excessively large individual), or **dwarfism** (excessively small individual).

Genes in Development

As mentioned earlier, the zygote nucleus has a complete genetic information or a blueprint for the formation of a complete individual. In other words, all genes which are required for the formation of different parts of an individual, are present within the zygote nucleus. As the embryo develops, the whole genome is transferred to each and every cell during cell division. This means, that each cell of the developing embryo will have the same set of genes. As development proceeds further we find that inspite of having the same complement of genes, different cells differentiate along different lines. For example, a muscle cell will acquire special kinds of proteins such as **actin** and **myosin** which will enable these cells to contract. The cells lining the stomach will produce mucous and specific enzymes which will be used in the digestive processes. The question is that how do these different types of cells differentiate along different lines inspite of the fact that all these cells have identical genes in their nuclei.

The most logical answer to this question will be that if the nuclei are identical in these cells then perhaps the cytoplasm may vary which in turn will selectively allow some genes to express themselves. Thus we find that both presence of the nucleus as well as cytoplasm is essential for the development of an individual. The importance of the nucleus and the cytoplasm in development can be demonstrated by the following experiments.

The role of nucleus was shown in an experiment using a large one-celled alga called *Acetabularia.* This plant is about 5-8 cm long, having a long stalk with a characteristic cap at the top (Fig.8.8). The nucleus of this alga lies in the part of the plant known as base. There are two species of this alga which differ in the shape and structure of their cap. *A. mediterranea* has an umbrella-like cap, whereas *A. crenulata* has warted or irregular cap. If the cap of these algae are removed they are regenerated. In the experiment under discussion the caps of the two individuals belonging to each of these species were removed following which the stalks of the individuals were also cut. The cut stalks were then switched and grafted on to the base of the individual of the other species. It was discovered that eventually the caps regenerated

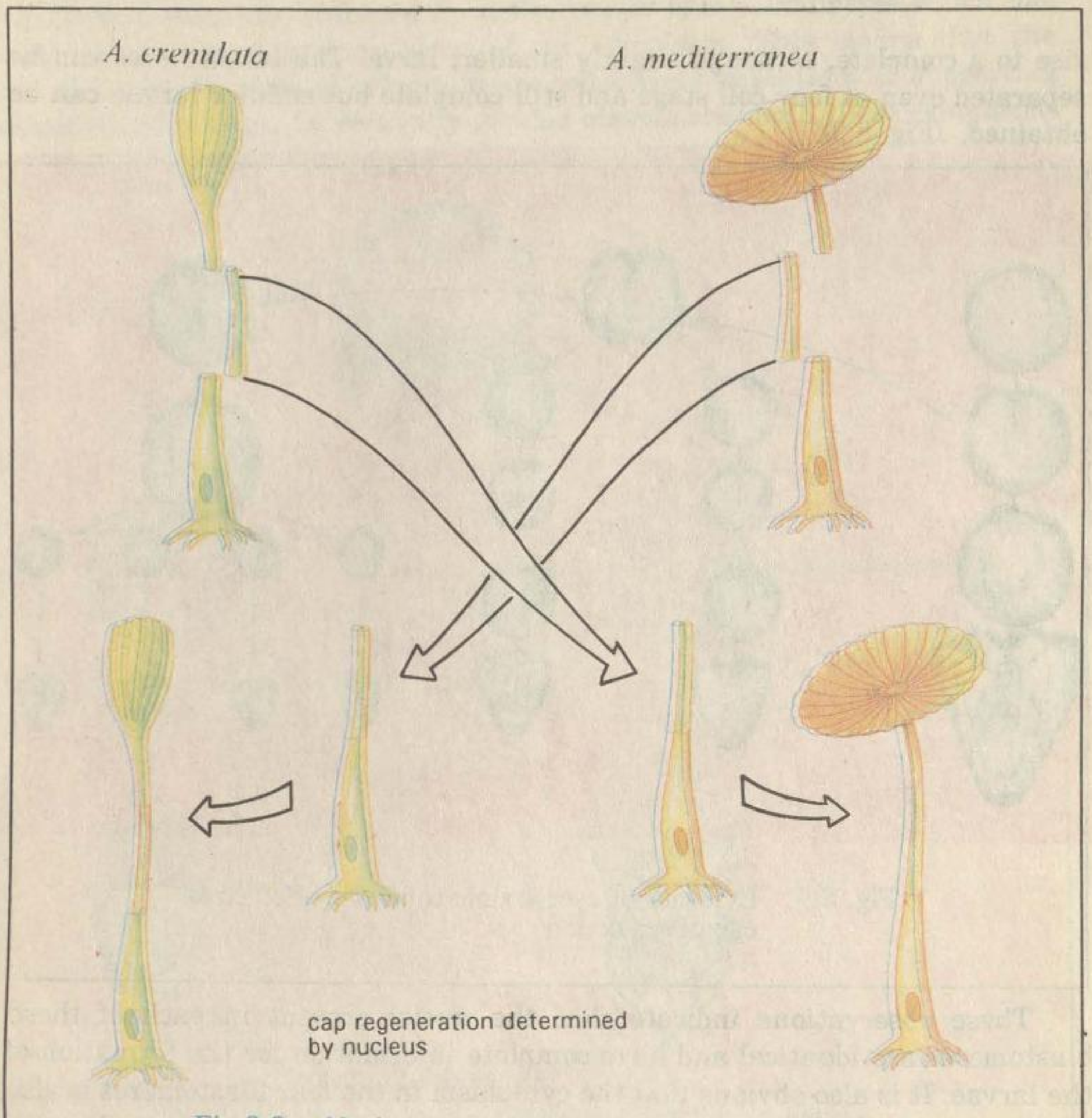

A. crenulata
A. mediterranea
cap regeneration determined
by nucleus

Fig 8.8. Nuclear control of cap structure in two species of Acetabularia

according to the type of the nucleus. This means that the genes present in the nucleus of both *A. mediterranea* and *A. crenulata* were able to express themselves even when the cytoplasm present in the grafted stem did not belong to their species.

The importance of cytoplasm in directing normal developmental processes was shown in another set of experiments. If the blastomeres of a sea urchin embryo were separated at two cells stage, it was discovered that each blastomere gave rise to a complete, although slightly smaller, larva. The blastomeres can be separated even at four cell stage and still complete but smaller larvae can be obtained. (Fig. 8.9).

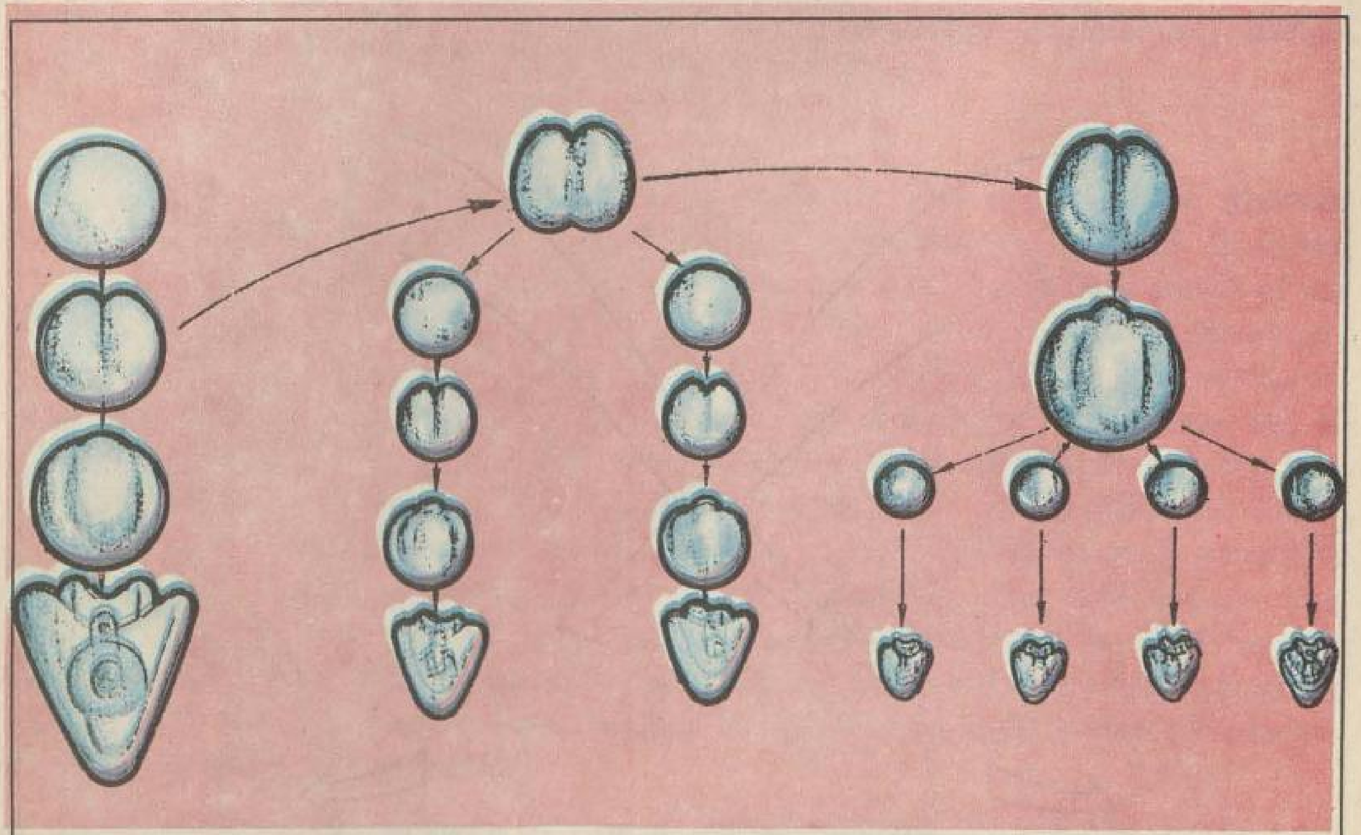


Fig. 8.9. Evidence of cytoplasmic control in a fertilized egg of sea-urchin.

These observations indicate that the nuclei present in each of these blastomeres are identical and have complete information for the formation of the larvae. It is also obvious that the cytoplasm in the four blastomeres is also similar so as to facilitate normal development. In a second set of experiments, an unfertilized egg of the sea-urchin was cut equitorially into two halves so that the cytoplasm of the two poles of the egg was isolated in one or the other of these halves. Both halves healed up after some time and appeared as normal cells (Fig. 8.10) although one of these halves lacked the nucleus. When both of these halves were fertilized artificially with sea-urchin sperms, it was discovered that none of these halves could develop normally, irrespective of the fact whether the zygote nucleus is present in the animal half or the vegetal half. This experiment showed that the cytoplasm present in the animal half or the vegetal half was not capable of supporting normal development by itself. On the other hand, in the previous set of experiments normal embryos were obtained from the two or four blastomeres which had arisen following vertical divisions of the cytoplasm. This means that the animal as well as vegetal cytoplasm are collectively important for supporting normal development. In vertically divided blastomeres both these cytoplasms were present and thus normal development was possible. On the other hand in horizontally divided zygote, each part contained only one type of cytoplasm which thus could not support normal development. These experiments clearly show the importance of cytoplasm in controlling normal development.

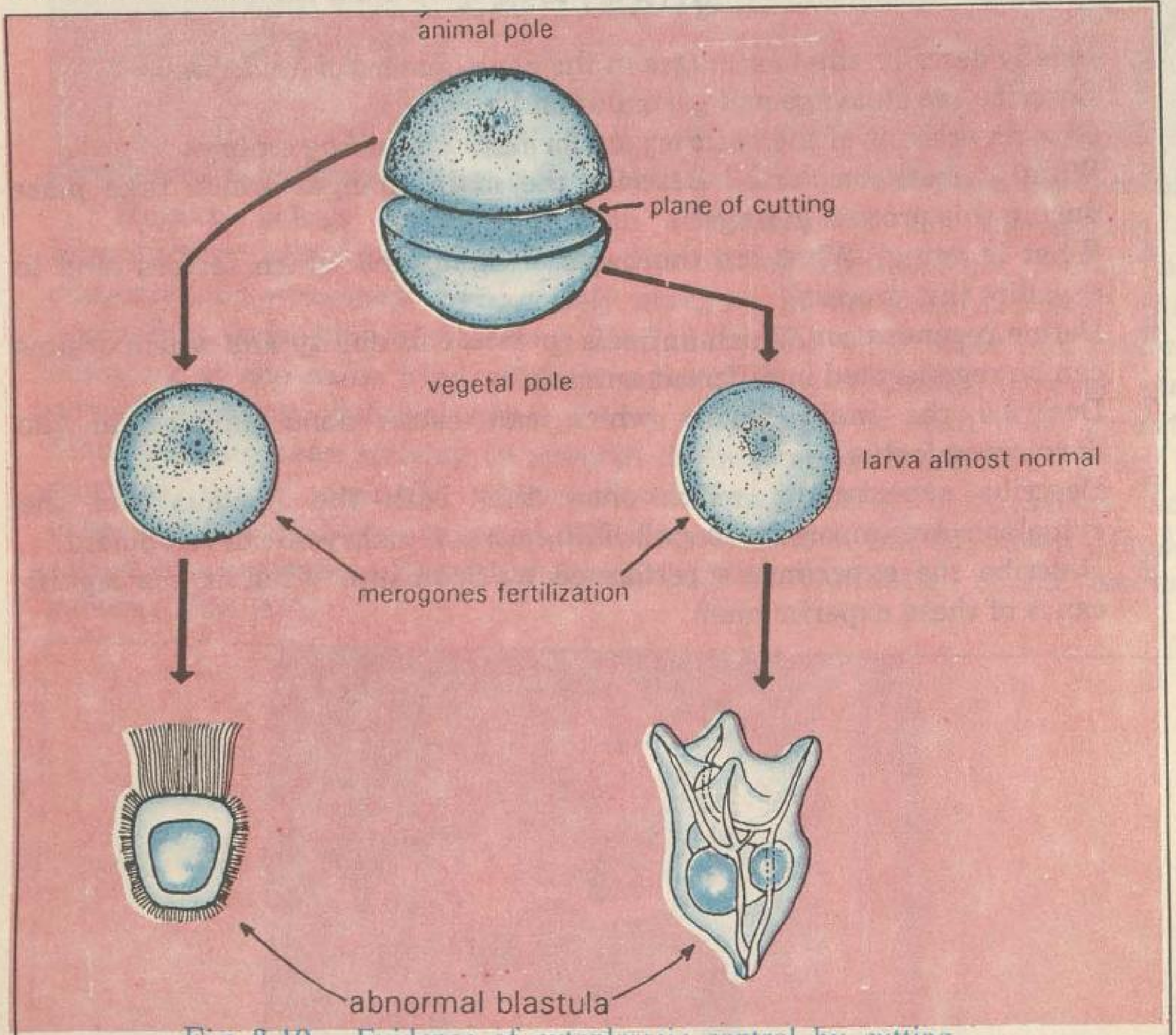


Fig. 8.10. Evidence of cytoplasmic control by cutting artificially unfertilized egg of sea-urchin.

From all these experiments described above, it is obvious that both nucleus as well as cytoplasm have an important role to play in normal development. The nucleus has all the genes which determine the characteristics of the individual species while the cytoplasm selectively **"turns on"** some genes and **"switches off"** others. This selective gene expression determines the fate of different cells in different directions.

QUESTIONS

1. Briefly describe the four stages in the development of an animal.
2. Describe the cleavage and gastrulation in frog.
3. Give an account of the basic organ formation in a frog embryo.
4. What is metamorphosis? Describe the main changes which take place during this process in frogs?
5. What is aging? What are the bases of aging and which factors tend to expedite this process?
6. Define regeneration.Which animals possess this ability and which organs can be regenerated in different animals?
7. Describe the main factors which can cause abnormalities in the developing foetus.
8. Describe experiments which show that both the nucleus and the cytoplasm are important in controlling normal embryonic development.
9. Describe the experiments performed by Spemann. What is the significance of these experiments?

PATTERNS OF HEREDITY

9

Human beings have long been interested in the mechanism of reproduction and inheritance. Many interesting explanations, though not supported by evidences, were widely accepted in the past. However, they knew that organisms of the same kind mate with each other and produce offspring of the same kind as their parents. The offspring, however, may never be exactly identical either among themselves or with their parents. Man has long been striving to unearth the mysteries of life. The history of genetics is an example which shows how careful observations and experimentations have explained difficult problems of life. However, Mendel solved the problems of heredity which laid the foundation of the modern genetics (Fig. 9.1.)

Fig 9.1. Gregor Mendel (1822-1884)

Gregor Johann Mendel (1822-1884) was born to a peasant family in a small village in Moravia, then a part of Austria, but now a part of Czechoslovakia. After some formal education, he was admitted to the Augustinian Monastry at Brun (now Brno) and was ordained as a priest at the age of 25. In the summer of 1854, he started working on garden peas

(Pisum sativum). He grew 34 strains of peas in the garden of his monastry at Brun and tested them for purity. Thus, he obtained lines which bred true to type generation after generation. In 1855 he started his series of experiments which led to his paper published in the Proceedings of the *Society for Natural History* In 1866.

Mendel's work was revolutionary and ahead of his time. His contemporaries failed to appreciate it. As a result, it remained unnoticed for many years until it was rediscovered in 1900. It is accepted now that Mendel's principles of inheritance are true, both for plants and animals. The reasons for Mendel's success in unravelling the mechanism of heredity, where the other workers of his time had failed, were:

(a) his approach, and

(b) his choice of experimental material

A) Approach

1. He adopted a systematic approach for his studies. He spent almost two years in producing 'pure' or 'true-breeding' varieties of the garden pea plant. Without obtaining the pure varieties, he might not have succeeded in discovering the principles which he did.
2. He studied one character or trait at a time and kept the numerical record of the results.
3. His approach was more statistical due to his mathematical background. Thus he always thought in terms of ratios.
4. He used a large number of plants at a time and thus got easily recognizable ratios.

B) Choice of Experimental Material

The use of garden pea plant by Mendel was evidently not accidental, as this plant had already been used by some other plant breeders of his time as well. The advantages of using this plant for experiment are as follows:

1. The plant is self fertilized in nature but controlled crossing can be made easily. However, the pollination can be controlled. For cross fertilization, the pollens from one plant can be transferred to the stigma of flowers of another plant.
2. The plant produces a large number of seeds.
3. It has many sharply defined inherited traits on the basis of which individual varieties are recognized (Fig. 9.2)

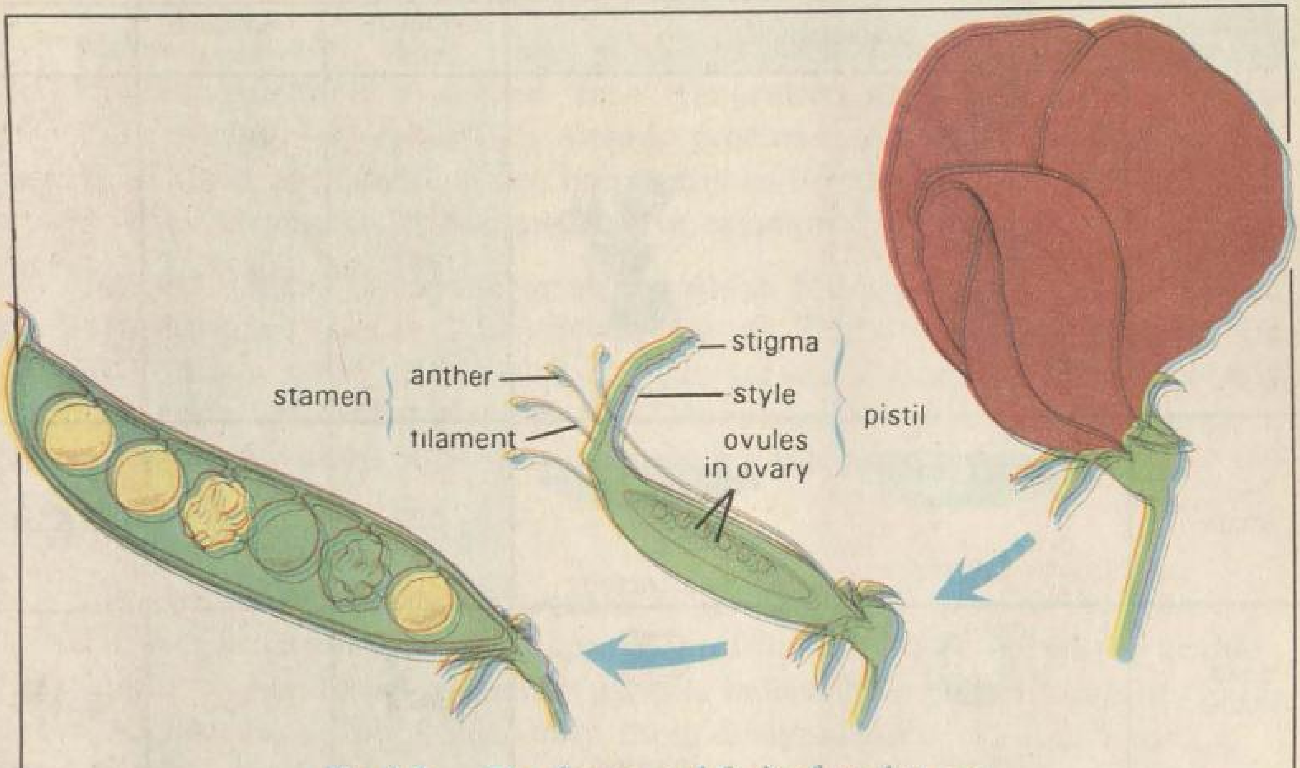


Fig 9.2. The flower and fruit of garden pea

Mendel began by working with only one trait at a time. He chose those traits that had strikingly different forms of expressions. Furthermore he chose seven such different pairs of traits and called them as contrasting pairs of characters, as shown in table 9.1

Table 9.1

Mendelian results of seven pairs upto F_2 generation in garden pea.

Characters	F_1	F_2	F_2 ratio
1. Round x wrinkled seeds	All round	5,474 round: 1,850 wrinkled	2.96:1
2. Yellow x green seeds	All yellow	6,022 yellow: 2,001 green	3.01:1
3. Red x white flowers	All red	705 red:224 white	3.15:1
4. Inflated x constricted pods	All inflated	882 inflated: 299 constricted	2.95:1
5. Green x yellow pods	All green	428 green:152 yellow	2.82:1
6. Axial x terminal flowers	All axial	651 axial:207 termianl	3.14:1
7. Tall x dwarf stems	All tall	787 tall: 277 dwarf	2.84:1

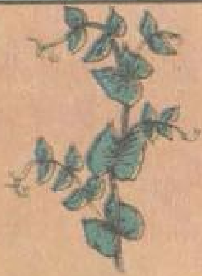
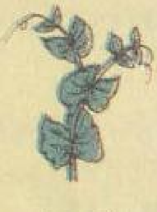
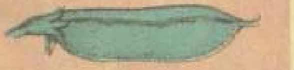
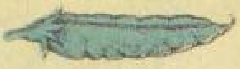
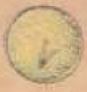
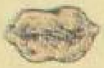
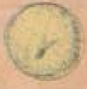
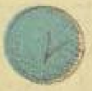
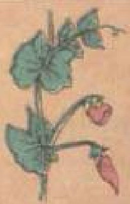
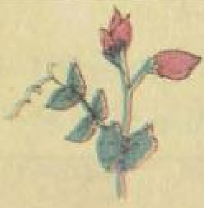
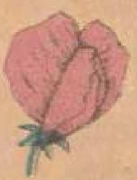
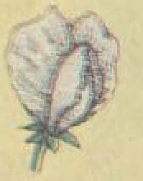
trait	characteristics		dominant form	recessive form	ratio
plant height	 tall	 dwarf	787	277	2.84:1
pod shape	 inflated	 constricted	882	299	2.95:1
seed shape	 round	 wrinkled	5474	1850	2.96:1
seed color	 yellow	 green	6022	2001	2.82:1
flower position	 axial	 **terminal**	651	207	3.14:1
flower color	 red	 white	705	224	3.15:1
pod color	 green	 yellow	428	152	3.01:1

Fig 9.3. Diagrammatic representation of various traits selected by Mendel in his experiments

Mendel chose to study these paired characteristics because they were easily distinguishable and bred 'true' generation after generation. A true breeding variety is one which always produces offspring identical to the parent. This is because they are habitually self fertilized in nature and as a result, the characteristics became fixed or constant (Fig.9.3).

Mendel noticed other characters in which the pea varieties also showed differences such as the leaf-size, flower-size etc. These differences however did not fall into a clear cut "either-or" categories. Therefore, Mendel wisely ignored such differences in his studies. Mendel's decision to limit the scope of his experiment was an important factor in his success.

Mendel's Experiments

Mendel made controlled crosses when the peas were in blossom. To prevent self fertilization in his experimental flowers, he removed the anthers from those chosen to act as female parents before their pollen receiving parts were fully mature. The pollens from those designated as pollen or/male (♂) parent were transferred to the stigma of the female (♀) parent at the appropriate time. Seeds were then allowed to mature. With the trait such as seed colour or seed shape, distinction could be made immediately. But, with traits such as plant height and flower colour, the seeds had to be sown and plants raised to maturity before the progeny could be classified. Hybridization experiments were carried through several generations and crosses were made between hybrids and pure breeding varieties. Mendel actually visualized clearly each problem to be solved and designed his crosses to solve these problems.

Principle of Segregation

Mendel started as simply as possible and raised pea plants that were ture breeding for different traits for use in his experiments. In one of his initial experiments, Mendel crossed ture breeding 'tall' pea plant with a true breeding 'dwarf'. He called this parental generation as the P_1 generation. All the offspring obtained in the next generation, designated as F_1 or **first filial generation** (F symbolized filial, from Latin, meaning progeny) were uniformly tall. The dwarf character had disappeared in the F_1 progeny. The F_1 tall were self fertilized and the F_2 progeny was raised. In this progeny, unlike the F_1, some plants were tall, like the original tall parent and others dwarf, like the dwarf parents. These results suggested that F_1 tall progeny, though apparently like the tall parent, nevertheless behaved differently. Given below is the diagrammatic representation of the cross made by Mendel.

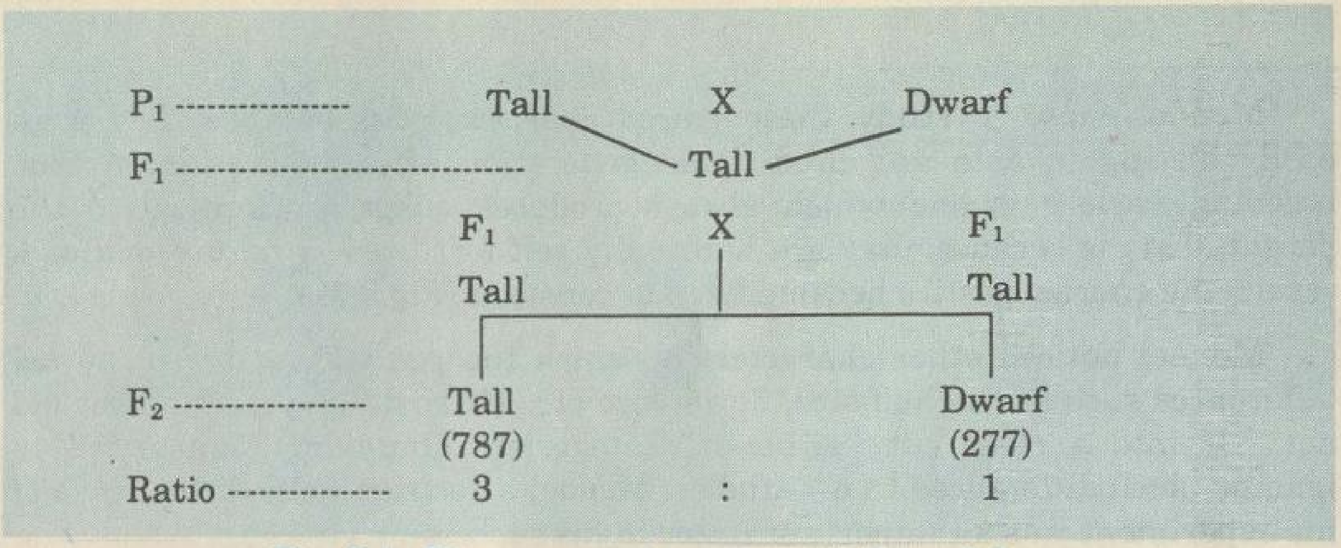


Fig. 9.4. Diagrammatic representation of the sweet pea cross made by Mendel

There were no plants intermediate in size. A careful study however revealed that when large number of plants were taken into consideration, about three fourth were found to be tall and one fourth dwarf. To be exact, Mendel's F_2 generation count of 1064 plants, consisted of 787 tall and 277 dwarf plants. This showed a nearly 3:1 ratio between talls and dwarfs. Closely similar results were obtained when the sexes of parent plants used in the experiments were reversed in the reciprocal crosses.

The experiment could have been concluded at this point but Mendel, in order to make his study more meaningful carried his experiment further and raised an F_3 generation from F_2 seeds. Mendel found that $^1/_3$ of the F_2 talls produced only tall plants whereas $^2/_3$ of the F_2 tall plants behaved like F_1 hybrid talls, thus producing both tall and dwarf plants in F_3 generation. The F_2 dwarf plants produced only dwarfs.

In other experiments, the remaining six of the originally selected seven pairs of contrasting characters, were also studied. One member of each pair expressed itself fully and thus dominated the other in the F_1 in the same way as tall dominated the dwarf in the first experiment. In the experiment described above Mendel concluded that when tall plants are crossed with dwarf, or when *round seeded* plants are crossed with *wrinkled seeded* plants, the tall or round seeded plants pass on some controlling factor through the gamete to the F_1 plants. The contribution of the male or the female gamete or the male and the female parents in this respect is equal and the end result in either case is the same.

The re-appearance of the characters in the F_2 generation, which had disappeared in the F_1, means that the character though not visible in the F_1

plants did exist in some masked form. Mendel called those traits as **dominant**, which make their appearance in F_1 while those that remain masked in F_1 but reappear in F_2 as **recessive.**

In an attempt to explain these facts, Mendel made a number of assumptions, which we now call as **hypotheses.** He actually began explaining his hypothesis by assigning symbols representing each trait. He assumed that the trait for tallness is caused by a dominant factor and represented it with the letter "T". The trait for dwarfness was caused by a recessive factor and represented it with the letter "t".

In genetical terms Mendel's factor which determine a given trait, such as stem height are called **genes.** The alternative forms of a given gene, such as tall versus dwarf characters are called **alleles** or **allelomorphs**. Thus a true breeding tall plant is represented as "TT" and dwarf as "tt". Later on the term **phenotype** was introduced to denote the appearance of the trait in the individual, and **genotype** to denote the genetic make up of the individual as far as a particular trait is concerned. Thus T T is the genotype whereas tallness is the phenotype of a true breeding tall pea plant.

In a pure breeding tall plant, all the gametes would contain factor T only (which we now call as the gene). During fertilization, T male gamete produced by pollen grains would fuse with T female gamete in an ovule. As a result F_1 tall individual is obtained which would carry the "T T" genes in it. Similarly the gametes produced by a dwarf plant, whether male or female, would carry t genes. On self fertilization the individuals produced would carry only "t t" genes. However, when a pure tall plant is crossed with a dwarf plant, it would receive both the genes T and t, one from the tall and the other from dwarf parent. Its phenotype would be tall, but its genotype would be different from the pure tall plant. Thus the F_1 plant would have both the genes T and t. Mendel knew that upon self fertilization such a tall plant would yield pea plants in a ratio of three talls to one dwarf. As Mendel had always obtained a precise ratio of 3:1 in the F_2 generation, whichever genes he may have studied, he was sure that the gametes were being produced in a mathematically precise way. He, therefore, made the following assumptions which were neither observations nor facts, but were statements. However, if true, he believed that these statements would provide an explanation for the observed results. These were:

1. Every trait is determined by discrete physical unit called factor. Each individual has two factors that together control the expression of a certain trait.

2. During the gamete formation, the pair of factors separate from each other, so that each gamete receives only one of the pair of factors of the parent. At the time of fertilization, the offspring receives one factor from the father and one from the mother to have a complete set of two factors. This is **Mendel's Principle of segregation.**
3. The factor controlling a particular trait can exist in different forms. Tall plants have a different form "T T" for the character controlling the stem length than the dwarf plants "t t". In pure line crosses one form such as (T T dominant) can completely wash the expression of the other form (t t recessive). However the dominant form of a factor does not alter the physical nature of the recessive form which can be passed unaltered into the individual's gametes.
4. In an organism with two different forms (alleles) of a given factor (T or t), the distribution of the allele into gametes is purely by chance. Any gamete has equal chances of receiving one allele or the other. Thus roughly equal number of gametes of each allele would be produced. The presence of alleles T T for a trait will produce true-breeding or **homozygous** individual, whereas two different alleles T t will produce a **hybrid** or **heterozygous** individual. The homozygous individual, produces only one type of gamete while the heterozygous produces two types of gametes in equal number each containing one or the other allele i.e. "T" or "t" of the two alleles.

Mathematically if the F_1 tall plant produces 100 male gametes and 100 female gametes then the gemetes would be in the proportion as shown in(Fig. 9.5)

		male gamete	
		T	t
female gametes:	T	50	50
	t	50	50

Fig. 9.5 Probable proportion of the formation of male and female gametes.

If all the gametes had an equal chance of combining with the other two, phenotypic classes of individuals in the ratio of 3:1 or three genotypic classes or individuals in the ratio of 1:2:1 will be produced. This can be verified by a checker board or simply by computing these probabilities as shown

Parents	Tt		X	Tt	
gametes	T	t		T	t
Frequencies	50	50		50	50
		or			or
Frequencies	0.5	0.5		0.5	0.5

Probability of T T genotype = T x T
0.5 x 0.5 = 0.25

T x t
Probability of T t genotype = 0.5 x 0.5 = 0.25 (from one side)
T x t
0.5 x 0.5 = 0.25 (from second side)
0.25 + 0.25 = 0.5

t x t
Probability of tt genotype = 0.5 x 0.5 = 0.25
Ratios of zygotes = 0.25, 0.50, 0.25
or
= 1 : 2 : 1

	T.5	t.5
T.5	TT 0.25	Tt 0.25
t.5	Tt 0.25	tt 0.25

Frequency	Genotype		Phenotype
0.25	TT	1	tall
0.25	Tt		tall
0.25	Tt	2	tall
0.25	tt	1	dwarf

Fig 9.6 Probable genotypic ratios (and their phenotypes), if all the gametes unite randomly.

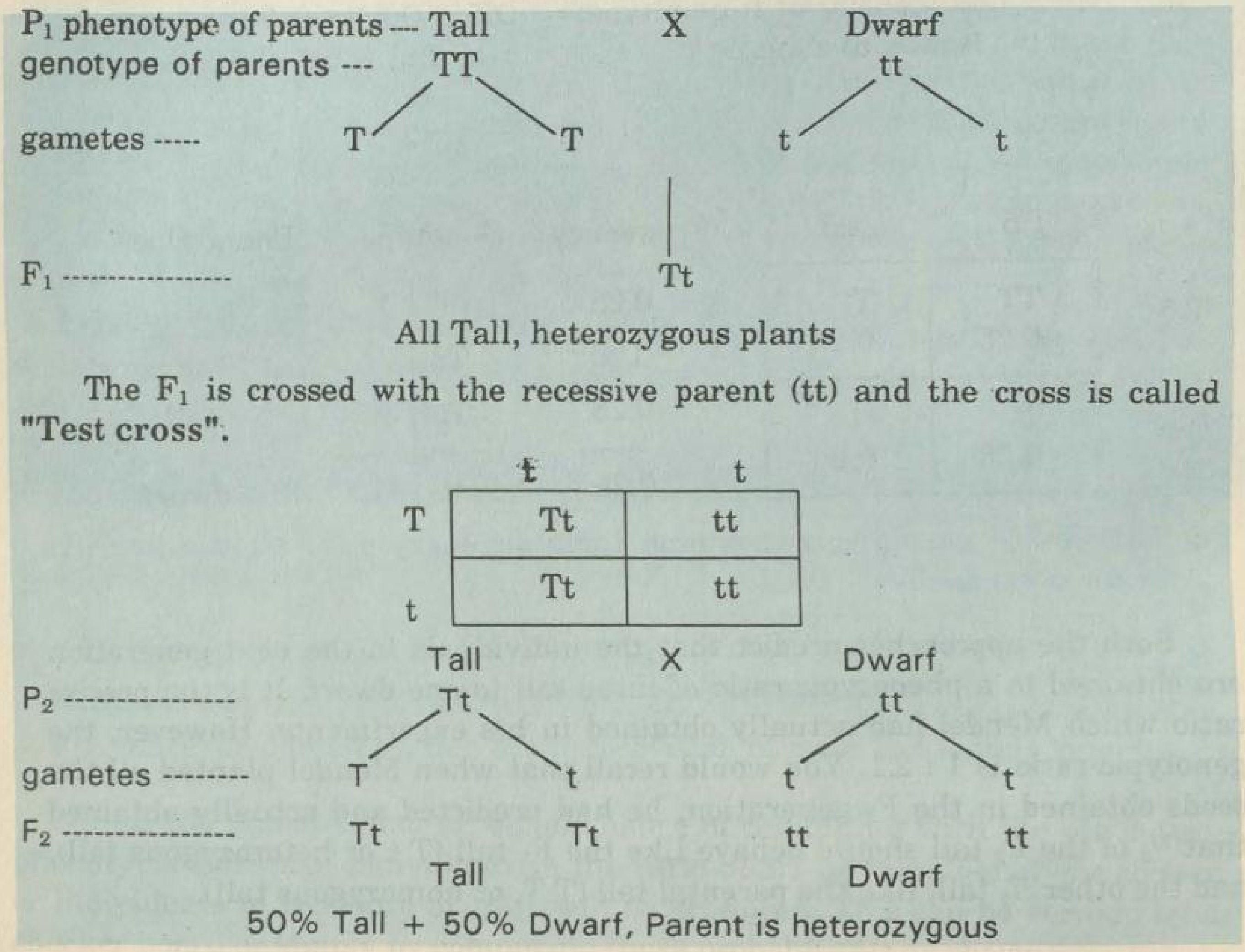
Both the approaches predict that the individuals in the next generation are obtained in a phenotypic ratio of three tall to one dwarf. It is the precise ratio which Mendel had actually obtained in his experiments. However, the genotypic ratio is 1 : 2:1. You would recall that when Mendel planted all the seeds obtained in the F_2 generation, he had predicted and actually obtained that $^2/_3$ of the F_2 tall should behave like the F_1 tall (T t or heterozygous tall), and the other $^1/_3$ tall, like the parental tall (T T, or homozygous tall).

The Principle of Law of regreagation can be defind as under:

"Whenever two different alleles of a trait are brought together in an individual, they stay together, but at the time of formation of its gametes, the two separate so that each gamete has one of the two alleles and not both".

Test-Cross: A Test of Mendel's Hypothesis

Mendel had been working on pea plants and making his hypothesis. He appreciated it fully that in order to test his hypothesis, he should try to predict the outcome of a breeding experiment which he had never performed. Mendel, therefore, crossed his F_1 tall (Tt) with a dwarf plant which would naturally be only homozygous (tt). If the hybrid F_1 plants had one allele for tallness and one for dwarfness, then one could be able to predict the outcome of the cross between Tt tall plants with homozygous recessive dwarf (tt) plants. On the basis of his hypothesis the heterozygous parent should produce equal number of T and t gametes while the homozygous dwarf parent only of one type i.e. t gametes. Mendel, therefore, prdicted that half of the plants from this cross would be tall and the other half dwarf. And this is what precisely happens when such a cross is made.



P_1 phenotype of parents --- Tall
X
Dwarf
genotype of parents --- TT
tt
gametes ----- T
T
t
t
F_1 ---------------- Tt
All Tall, heterozygous plants

The F_1 is crossed with the recessive parent (tt) and the cross is called **"Test cross".**

	t	t
T	Tt	tt
t	Tt	tt

Tall
X
Dwarf
P_2 ---------------- Tt
tt
gametes -------- T
t
t
t
F_2 ---------------- Tt
Tt
tt
tt
Tall
Dwarf

50% Tall + 50% Dwarf, Parent is heterozygous

Fig. 9.7 Diagrammatic representation of a test cross.

Thus it further provides support to Mendel's law of segregation.

One can note that this cross and the original monohybrid cross have the same parental phenotypes, one parent being tall and the other dwarf. However, the offspring obtained from the two crosses differ. They are all tall in the original cross involving one trait at a time (also called the monohybrid cross), whereas the tall and dwarf are in a ratio of 1: 1 in the second cross. In many actual breeding experiments one cannot tell whether an organism displaying a dominant pyhenotype is homozygous or heterozygous for the character. Cross fertilization of a phenotypically dominant individual with a homozygous recessive individual is called a **test-cross.** It can be used to test the homozygosity or heterozygosity of the dominant parent. When crossed with a recessive, a homozygous dominant produces all phenotypically dominant offspring, whereas a heterozygous dominant yields half dominant and half recessive offspring.

Other Examples of Single Trait Inheritance

As has already been discussed, Mendel's principles were worked out on pea plants only. Without doing similar experiments on other organisms, however, we cannot be sure if the hypothesis established by Mendel on garden pea could be applied in general. For this purpose let us study an example from the animals e.g. guinea pigs.

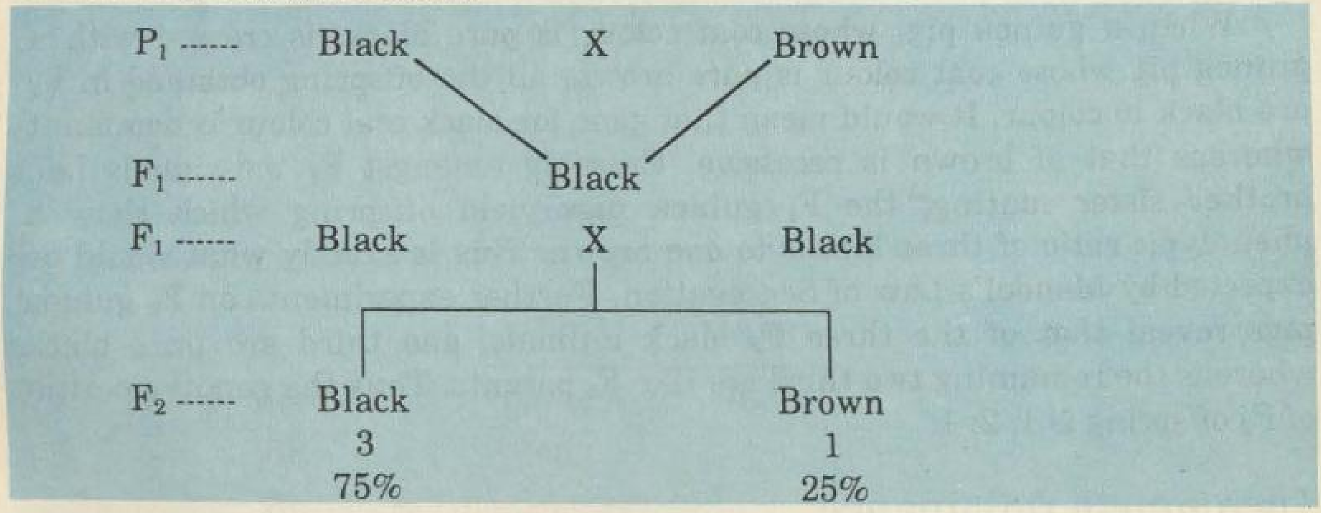
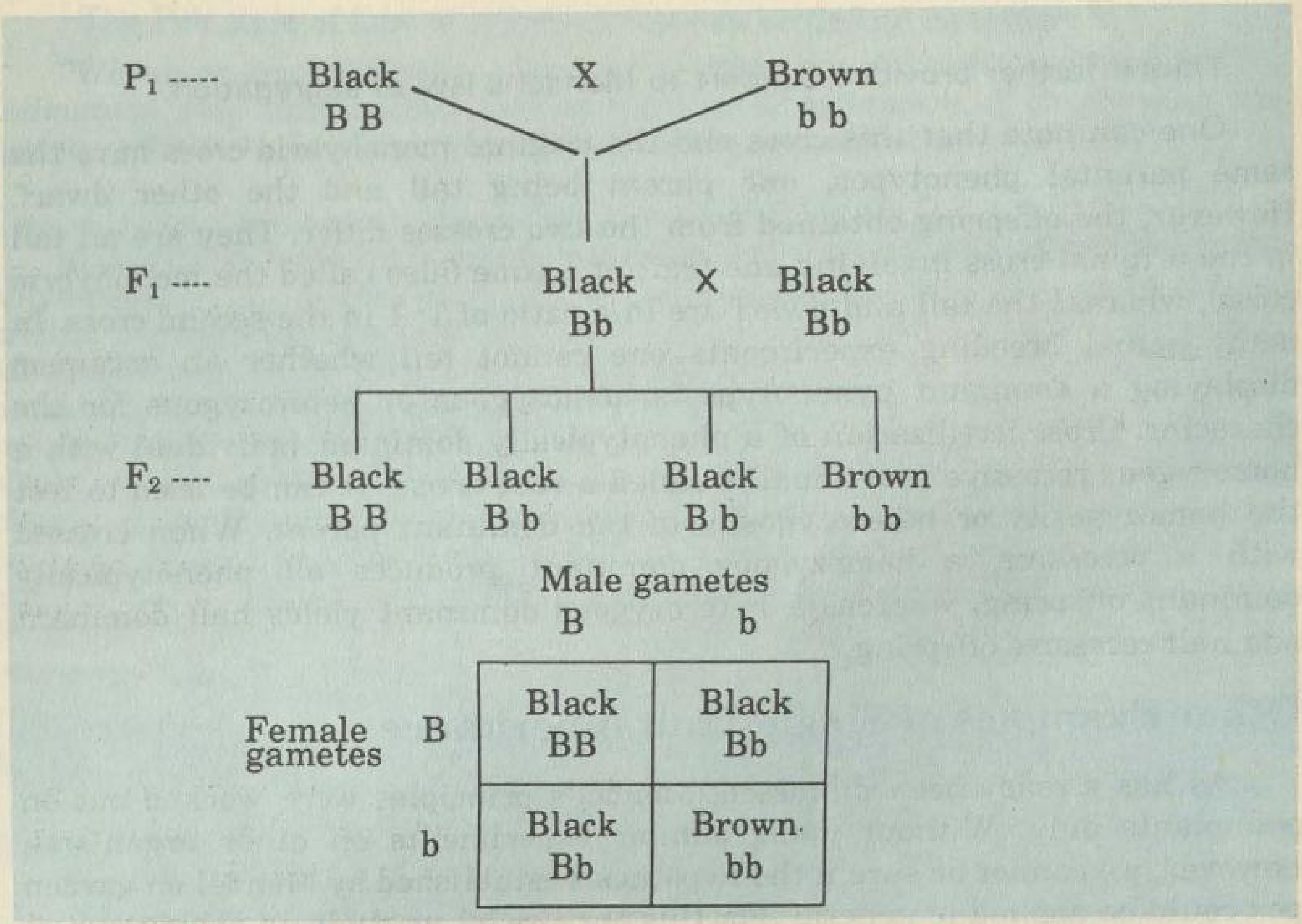


Fig 9.8 Phenotypic results of a cross between a "pure" black and a "pure" brown guinea pig.

This cross is explained along with genotypes as shown on next page



	B	b
B	Black BB	Black Bb
b	Black Bb	Brown bb

Fig. 9.9. Genotypic results of the cross shown infigure 9.8

When a guinea pig, whose coat colour is pure black, is crossed with a guinea pig whose coat colour is pure brown, all the offspring obtained in F_1 are black in colour. It would mean that gene for black coat colour is dominant whereas that of brown is recessive. Crossing amongst F_1 individuals i.e., “brother-sister mating,” the F_1 guinea pigs yield offspring which show a phenotypic ratio of three blacks to one brown. This is exactly what would be expected by Mendel's Law of Segregation. Further experiments on F_2 guinea pigs reveal that of the three F_2 black animals, one third are pure black whereas the remaining two third are like F_1 parents. Thus the genotypic ratio of F_2 offspring is 1: 2: 1.

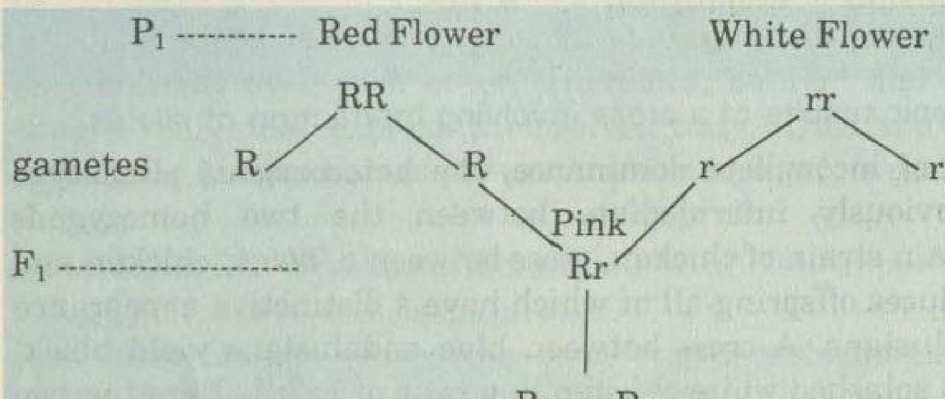
Incomplete Dominance

The seven characters of garden peas that Mendel followed in his experiments were all of the kind in which one allele showed complete dominance over the other. Only a few of the characteristics show this mode of inheritance while a large majority does not. In such instances, it may be improper to use the words dominant and recessive. A few of such examples are:

Red and white colour of flowers in Japanese four-O'clock plants *(Mirabulus jalapa)* and skin colour in short horn cattle.

The inheritance in which heterozygous individuals clearly show effects of both alleles is termed as **incomplete dominance.** In many of such cases the heterozygous individuals have a phenotype that is actually intermediate between the phenotypes of homozygous individual for the other.

Four O'clock plants with red flower and those with white flower, when self pollinated, breed true. A cross between red flowered and white flowered plant, however, neither yeilds red nor white coloured flowers in F_1 generation. Surprisingly, all the plants in F_1 carry pink coloured flowers, a character which neither of the parents possessed. However, the pink coloured plants on self fertilization yield red and white coloured plants alongwith pink plants in a ratio of 1: 2: 1.



Rr x Rr

F_2 ---------------------

	R	r
R	RR (Red)	Rr (Pink)
r	Rr (Pink)	rr (White)

Genotype	Phenotype	Ratio
RR	Red	1
Rr Rr	Pink	2
rr	White	1

Fig. 9.10. Genotypic and Phenotypic results of a cross between red flowered and white flowered *Japanese four O' clock* plants.

This is the genotypic ratio which is normally expected in a monohybrid cross. Therefore, in cases with incomplete dominance of this type the genotypic and phenotypic ratios are the same.

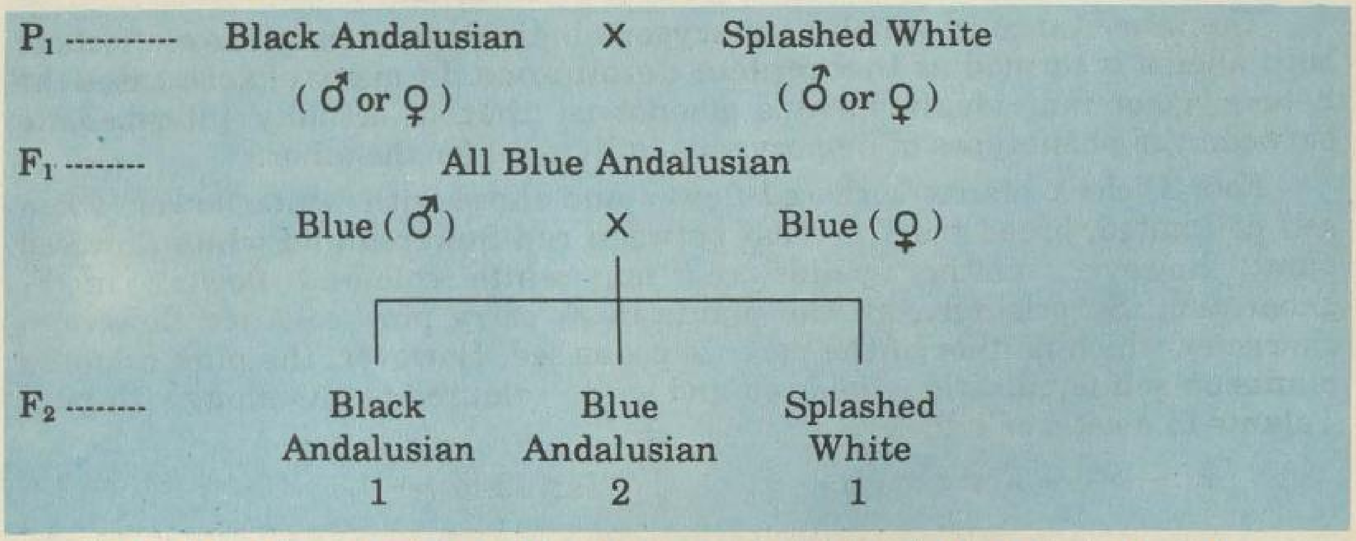

P_1 ----------- Black Andalusian X Splashed White
(♂ or ♀) (♂ or ♀)
F_1 -------- All Blue Andalusian
Blue (♂) X Blue (♀)
F_2 -------- Black Andalusian 1
Blue Andalusian 2
Splashed White 1

Fig.9.11 Phenotypic results of a cross involving Interaction of alleles.

In certain cases of incomplete dominance, the heterozygous phenotype may not be so obviously intermediate between the two homozygous phenotypes. In a certain strain of chicken, cross between a '*black*' chicken and '*splashed white*' produces offspring all of which have a distinctive appearance known as blue andalusians. A cross between blue andalusians yield black, blue andalusians and splashed white chicken in a ratio of 1: 2: 1. Here the two alleles, one for black and the other for white, are actually interacting to produce a phenotype somewhat different which might be expected as the intermediate colour between black and white.

Multiple Alleles

From the discussion so far, the impression one gathers is that the genes can have only two allelic forms which may exhibit either a dominant or recessive or an incomplete dominance relationship to each other. This, however, is not the whole truth. Mutations can produce many different alleles for each gene and thus the genes may occur in any number of allelic forms. Under normal circumstances, however, the maximum number of alleles for each gene that an individual can possess, is only two. This is because each individual has only two doses for each gene. Such alleles that may exist in more than two different forms are called **multiple alleles.**

A well known example of multiple alleles in human beings is that of the blood groups. A blood group that a person may have, depends upon the presence or absence of certain specific substances on the red blood cells. These substances are antigens and are of two kinds: Antigen A, and Antigen B.

A person with antigen A has a blood group A, and that with antigen B, has blood group B. A person who has neither antigen A nor antigen B in the blood cells has blood group O, while a person having both antigens A and B falls in blood group A B. It is interesting to find that the trait of blood group in human beings is under genetic control.

It is now known that there are three alleles responsible for this trait. gene I^A is responsible for the synthesis of antigen A. Gene I^B leads to the synthesis of antigen B while its alternate gene *i* synthesizes no antigen at all. As only two alleles can occur in one individual, therefore, three alleles can have only four possible combination, as shown in table 9.2

The alleles I^A as well as I^B are dominant over allele i, but neither I^A nor I^B is dominant over each other. Therefore, both I^A and I^B when present in a single individual express themselves fully. Thus the various blood groups which the human beings possess are summarized as under:

Table 9.2

Table 9.2. Possible combinations of alleles, of the blood groups, showing the genotypes and antigens on R. B. C

Blood types	Antigen	Genotypes
Blood group A	A	I^A I^A (homozygous)
	A	I^A i (heterozygous)
Blood group B	B	I^B I^B (homozygous)
	B	I^B i (heterozygous)
Blood group AB	A & B	I^A I^B
Blood group O	no antigen	i i

As the four blood groups are genetically controlled, therefore, they are not changed during the life time of any human being.

Blood typing is often used as a source of evidence in establishing paternity. For example, a man with blood type O cannot be the father of a child with blood type A, whose mother is of blood type B. The child's true father could either be with group A or AB. This is because the child must have received its allele I^A from its father, and the man with blood type O has no I^A allele. However, it is sometimes possible to say with certainty that a particular man is not the father of a particular child. The converse that is a particular man is the father of a particular child is not possible to conclude with certainty. The blood types, therefore, are only of a limited value in this respect.

Inheritance of Two Traits

Mendel's experiments on garden peas were not limited to single character, but sometimes involved two or even more than two of the characters listed in table 9.1 In one of such experiments, he made a cross involving two traits: i.e. seed colour and seed shape. He had ascertained already that his experimental plants with yellow and round seeds bred true to type, as were the plants with green and wrinkled seeds. When these plants were cross pollinated among themselves, all the F_1 offspring bore yellow and round seeds. This was no surprise to Mendel, as the separate single trait crosses had already shown that yellow seed colour behaved as dominant over the green and that the round seed shape dominant over the wrinkled. Mendel allowed the F_1 plants to self fertilize. He could have predicted three yellow round to one green wrinkled plant in F_2 generation. The F_2 generation, however, consisted of not only the parental combinations, but plants showing seeds with yellow wrinkled and green round trait had also appeared. The F_2 progeny appeared in the ratio of 9: 3: 3: 1 for the four phenotypes, as shown in Fig 9.12

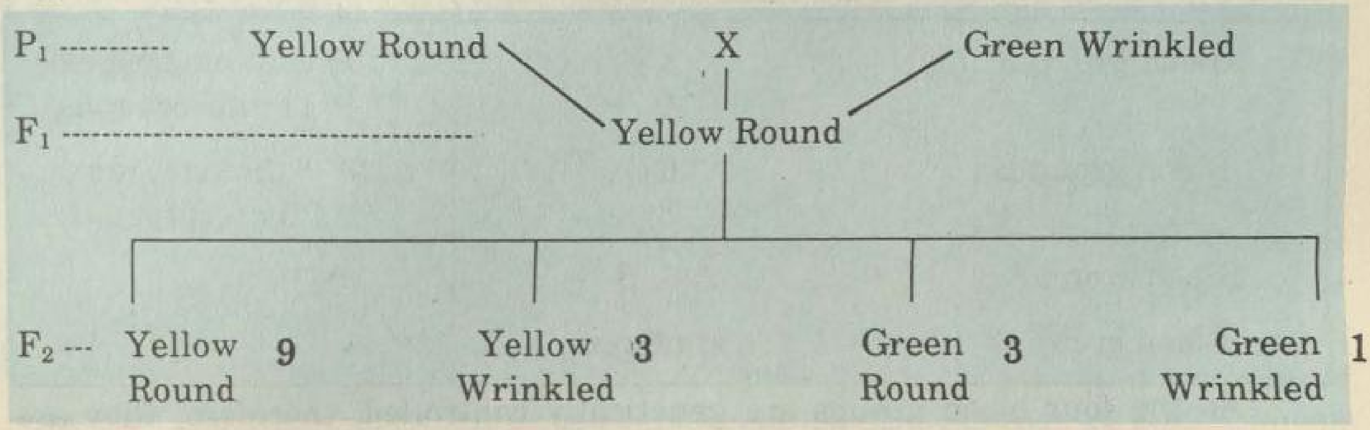


Fig 9.12 Phenotypic results of a cross involving two traits in sweet pea plant.

What Mendel actually obtained consisted of

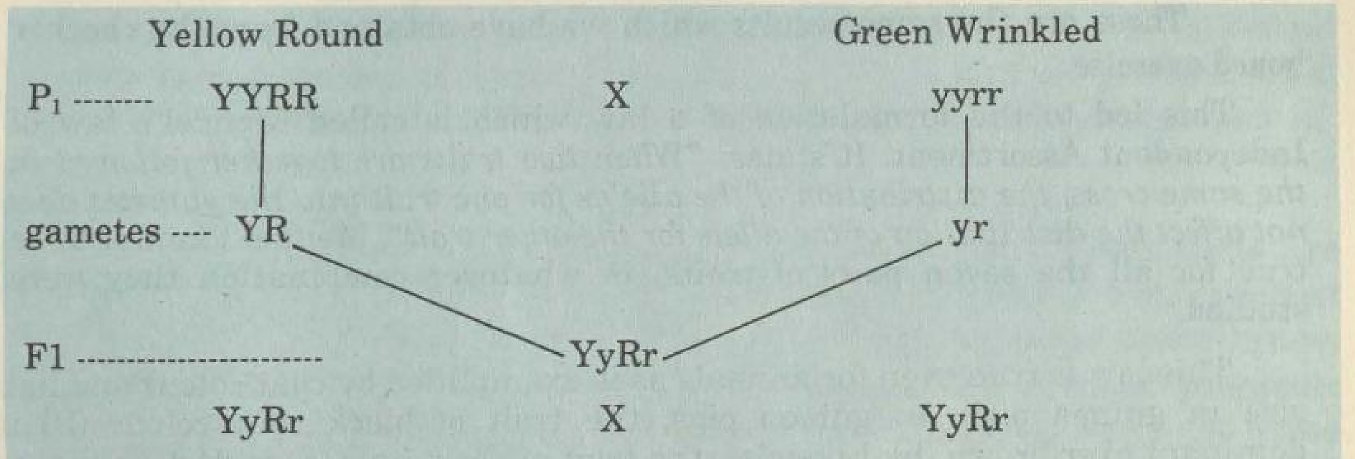
Yellow Round = 315 Yellow Wrinkled= 101

Green Round = 108 Green Wrinkled= 32

This experiment revealed that in crosses involving two traits (**Dihybrid cross**) some phenotypically new plants, unlike either of the original parental plants, were produced. In other words, it demonstrate that the genes for seed colour and seed shape did not necessarily stay together in the combination in which they occured in the parental generation. Instead they assorted independent of each other. Mendel, therefore, concluded that:

When two contrasting pairs of traits are followed together in the same cross, alleles in each pair are inherited or assorted independent of each other. This is called as law of Independent Assortment

Using the checker board method for the complete cross, a 9: 3: 3: 1 ratio can be shown as below:



Sperms

F_2 ------	YR	yR	Yr	yr
YR	YYRR	YyRR	YYRr	YyRr
yR	YyRR	yyRR	YyRr	yyRr
Yr	YYRr	YyRr	YYrr	Yyrr
yr	YyRr	yyRr	Yyrr	yyrr

Eggs

Fig 9.13 Genotypic results of dihybrid cross shown in fig 9.12 by checker board method.

A dihybrid cross can also be worked out using probability theory. We can calculate the probabilities of the various phenotypes in F_2 generation. From the results of the inheritance of single trait, we know that $^3/_4$ of F_2 offspring will be yellow and $^1/_4$ green. Further that $^3/_4$ of the offspring will be round and $^1/_4$ wrinkled. Multiplication of these independent probabilities will produce the F_2 offspring as below:

Table 9.3

Table 9.3. Working out of various probabilities in a dihybrid cross.

Seed colour		Seed shape	Frequency of F_2 offspring
3/4 yellow	x	3/4 round	9/16 yellow and round
1/4 green	x	3/4 round	3/16 green and round
3/4 yellow	x	1/4 wrinkled	3/16 yellow and wrinkled
1/4 green	x	1/4 wrinkled	1/16 green and wrinkled

These are the same results which we have obtained from the checker board exercise.

This led to the formulation of a law which is called Mendel's law of Independent Assortment. It states: "*When two traits are together followed in the same cross, the distribution of the alleles for one trait into the gametes does not affect the distribution of the allele for the other trait*". Mendel found it to be true for all the seven pairs of traits, in whatever combination they were studied.

This law is true even for animals as is examplified by coat colour and hair size in guinea pigs. In guinea pigs, the trait of black coat colour (B) is dominant over brown (b). Likewise, the trait of short hair (S) is dominant over long hair (s). When a guinea pig with pure black and short hair is mated with one which has brown and long hair, then all the offspring obtained in F_1 show black coat colour and short hair. However, when the F_1 individuals are mated among themselves to raise the next progeny, offspring as shown in (fig. 9.14.) are obtained (attempt the cross as an example). It is interesting to note that whereas some individuals in F_2 showed the parental combinations of the trait, new combinations of the traits appeared in others. For example, some animals were black with long hair coat, others were brown in colour with short hair. The four types of animals appeared in a phenotypic ratio of 9: 3: 3: 1.

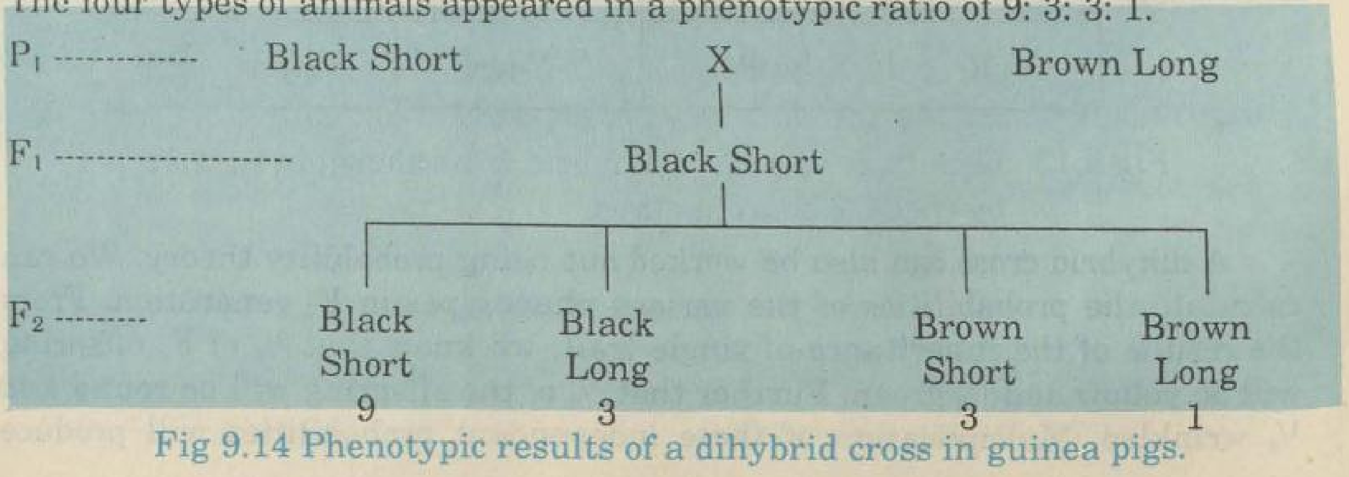


Fig 9.14 Phenotypic results of a dihybrid cross in guinea pigs.

The Law of independent assortment is, therefore, not peculiar for pea plants alone, as it holds good for guinea pigs and other organisms too. However, we shall study later on that it is not always so and there are certain exceptions to it.

Continuously Varying Traits

Mendel, during his experiments worked with traits that showed distinctive contrasts, i.e., tall against dwarf, smooth against wrinkled, yellow against green and so on. There were no intermediate phenotypes between these contrasting characters. However, most of the traits do not vary in a clear cut, easily distinguishable qualitative way. In other words, most of the traits vary quantitatively among different individuals, e.g., the height in human beings, colour of kernels in corn, the skin colour in humans. The variations in these traits cannot be accounted for on the basis of single pair of genes.

One of the explanations that can be put forth is that such traits are controlled by two or more than two separate pairs of genes which manifest themselves in an additive fashion. This is known as **polygenic inheritance.** It results in yielding continuously varying traits. The simplest polygenic situation occurs when there are at least two gene pairs that affect the same trait in a cumulative manner. In certain types of wheat, with coloured kernels, for example, there are two gene pairs for the kernel colour, each with alleles R and r. To distinguish the two pairs, subscript 1 and 2 are used for each gene allele. Thus the dominant alleles in this particular case are written as R_1 and R_2, while the recessive as r_1 and r_2. The allele R, regardless of the suscript, adds one dose of pigment, whereas allele r produces no red pigment. If it were a single trait inheritance then the colour of the kernel would depend on the genotype as follows: RR = red, Rr = pink, rr = white.

It would mean that a maximum of three grades in the intensity of the colour would be possible. However, with two genes, the kernel colour shows more grade in the colour intensity, depending upon the presence of number of domimant alleles of the two genes. With all the dominant alleles (R_1 R_1 R_2 R_2) four doses of pigments are produced, thus the colour of the kernel will be dark red. With all the recessive alleles (r_1 r_1 r_2 r_2) no pigment is produced at all, and the kernel colour remains white. The intermediate number of dominant alleles yields intermediate intensities of red colour.

The inheritance of height or skin colour in man, is more complex involving many pairs of genes. Tallness, for example, is recessive to shortness.

Thus, more the dominant alleles in the genotype, shorter the individual will be. The same holds for the additive effect of the recessive alleles which determine the height. Because of the many pairs of the genes involved, the height of the adults has a wide range of variation. However, it is not possible to determine the exact number of gene alleles involved in the inheritance of quantitative characters. Further, one must also bear in mind that some of the traits, like height and skin colour in human beings, are also modified to some extent by a number of environmental and physiological factors.

Human Inheritance

It was realized quite early that Mendelian laws of inheritance apply to all plants and animals including humans. Although of great interest to biology, the study of inheritance of characteristic in man is beset with many difficulties. This is partly because of the fact that the geneticists prefer to perform experiments on true breeding lines which can be obtained after a number of generations of inbreedings. This, of course, is not possible in man. Further, the geneticists repeat the crosses many times to obtain maximum possible number of offspring. These are some of the conditions which are very difficult to overcome. Even then, by carefully tracing the inheritance in human beings by the well known pedigree method, a great deal has been learnt about the inheritance of number of traits. The inheritance of some of the traits is mentioned in table. (9.4)

Table 9.4

We will mention below the inheritance of a few of the traits in human beings.

Dominant	Recessive
normal	extreme myopia
normal	night blindness
normal	albinism
normal	polydactyl
A and B antigens	no A or B antigens
normal	sickle cell
Rh antigen	no Rh antigen
free ear lobe	attached ear lobe
normal	diabetes mellitus

Some traits in man that are inherited in a Simple Mendelian Fashion.

Blood Types

We have already referred to the inheritance of blood groups A, B, AB and O. There are many more genes which are known to affect the blood groups. One of these is responsible for R^h blood factor (R^h stands for Rhesus monkey, the animal in which the antigen was first discovered). Antigen R^h is produced as a result of a dominant gene R^h whereas its recessive allele r^h does not produce any antigen. The possible genotypes and phenotypes in human beings in relation to this gene, therefore, can be:

Phenotype	Genotype	Antigen
Rh^+ or Rh — positive	$R^h R^h$, $R^h r^h$	Antigen R^h present
Rh^- or Rh — negative	$r^h r^h$	Antigen R^h absent

In comparison to blood groups A, B, AB and O, where a person's blood plasma may contain anti-A or anti-B antibody without stimulation by the corresponding antigen, it will not contain any antibody against the Rh antigen, unless the body is stimulated by exposure to Rh antigen. Therefore, the blood of a normal Rh negative person contains neither Rh antigen on its cells nor Rh antibody in its plasma. However, if an Rh negative person is mistakenly given R^h positive blood, this exposure to the antigen will stimulate his plasma cells to begin producing antibodies. If the same person is later on given another transfusion of Rh positive blood, the antibodies already present in his plasma will react with the antigen in the blood donated, and the person may die. It is, therefore, of vital importance that not only the blood groups A, B, AB and O, but also the Rh factor of both the donar and the recipient be matched before transfusion.

Rh factor is of particular importance in certain cases of pregnancies. If an Rh negative woman ($r^h r^h$) marries an Rh positive man ($R^h R^h$ or $R^h r^h$), some of their children may be heterozygous ($R^h r^h$) and thus have an Rh positive phenotypes. If the red blood cells from the blood of such a foetus seep through the placenta into the circulatory system of the mother, they can stimulate the production of antibodies against the Rh antigen. Now, if these antibodies seep back into the circulation of the foetus, these antibodies will start destroying the red blood cells of the foetus. This may harm the foetus leading to miscarriage. The baby born alive in such cases may suffer from severe anaemia or jaundice, whose only chance of survival lies in the complete replacement of its blood which is free of anti-Rh antibodies.

Skin Colour

The inheritance of skin colour is a case of polygenic inheritance, being controlled possibly by eight pairs of genes, all of which assort independently of one another. Each allelic pair shows incomplete dominance to its alternate. The black colour of the skin is due to the dark pigments, whose production is controlled genetically. That is why many grades of complexions are met with between white and black. Exposure to sunlight, however, does modify the shade of the skin colour, but its effect is temporary.

Eye Colour

The colour of the eye is due to the amount of brown pigment present in the iris. If it is free of pigment, the eye colour is blue. The recessive genes prevent the formation of this pigment, whereas their dominant alleles produce the pigment. Thus, the colour of the eyes depends upon the number of dominant genes for the eye colour. Hence the unpigmented eye condition is recessive.

Baldness

Baldness is also hereditary, being dominant in males and recessive in females. Thus it is more common in men than in women.

Tongue Rolling

Some people have the ability to roll the tongue into a distinct U shape, when it is extended from the mouth. This trait is due to a single dominant gene. The person possessing its recessive allele, cannot do the same.

Diabetes Mellitus

This disease, whereby the body becomes unable to utilize the sugar properly, is caused by a recessive gene. However, the severity of the disease depends upon the environmental conditions as well.

In addition, there are some mental diseases which are hereditary in nature, like schizophrenia, phenylketoneuria etc. Each of these diseases is caused by a single recessive gene. Some other mental diseases as Down's syndrome, Turner's syndrome or Klinefelter's syndrome are caused due to the abnormal chromosomal number.

QUESTION (PROBLEMS)

1. In the pea plant, tall (T) is dominant to dwarf (t) and green pods (G) dominant to yellow pods (g). List the types of gametes and offspring that would be produced in the following crosses:
   (a) TtGg X Tt Gg
   (b) TtGg X Tt GG
   (c) Tt Gg X Tt gg

2. In certain cattle, hair colour may be red (homozygous dominant RR) white (homozygous recessive rr) or roan (heterozygous Rr).
   (a) When a red bull is mated to white cow, what genotype and phenotype of offspring would be obtained?
   (b) If one of the offspring is mated to a white cow, what genotype and phenotype of offspring would be produced? What would be their proportions?

3. Explain Mendel's Law of segregation by giving examples you have studied.

4. Discuss in detail the Law of Independent Assortment. Explain your results by making a checker board.

5. Define the following terms:
   (a) gene, (b) allele, (c) dominant, (d) recessive,
   (e) homozygous (f) heterozygous (g) genotype, (h) phenotype.

6. Explain what is a test cross? Give its significance.

7. What are considered to be the reasons of Mendel's success in unravelling the mechanisms of heredity?

8. What are multiple alleles? Explain it with an example that you have studied.

9. Is it true that an allele always shows a complete dominance over its counterpart? If not, explain with some suitable examples.

10. If the new born babies get mixed up in a hospital, how could you determine their parentage from the information given below. Also give the possible genotypes of the six persons.

Baby I	Type	O
Baby II	Type	B
Mrs. Zafar	Type	A

Mr. Zafar	Type	AB
Mrs. Saleem	Type	A
Mr. Saleem	Type	A

11. How would you explain the inheritance of the skin colour in human beings or the colour of kernel in corn?

12. Write in detail the importance of inheritance of Rh factor in human beings, particularly if an Rh^- woman marries an Rh^+ man.

13. Pick out the heterozygous and homozygous from the following genotypes. Separate the genotypes having the same phenotype. Also pick out the series of multiple alleles and the genes for which only two alleles are given:

I^AI^A, BB, Aa, AA, $I^A I^B$, I^Bi, Rr, ii, rr, I^Ai

THE CHROMOSOME THEORY OF HEREDITY

10

The Relationship of Genes and Chromosomes

Mendel's results led him to conclude that the inheritance of characters in living organisms is controlled by numerous paired factors or elements. Now we call these factors or elements as **genes**. One member of each pair comes from the male parent and the other from the female. When an individual is ready to reproduce, the members of each gene pair segregate or separate and only one member of each pair enters the sperm or the egg. Mendel did not know what genes were and where they were located. W.S. Sutton in 1902 pointed out the relationship of genes and chromosomes. Table-I shows the parallel behaviour between genes and chromosomes.

Table 1: Parallel behaviours between genes and chromosomes.

Behaviour of genes	Behaviour of chromosomes
1. The genes that control a particular trait occur in pairs.	1. The chromosomes also occur in pairs.
2. Gametes have half the number of genes than body cells.	2. Gametes have half the number of chromosomes than body cells.
3. In fertilization gametes unite, restoring the original number of genes.	3. In fertilization gametes unite, restoring the original number of chromosomes.
4. The individual genes remain unchanged from one generation to the next.	4. The individual chromosomes retain their structure from one generation to the next.

5. The number of possible gene combination can be calculated or there is independent assortment of genes.	5. The number of possible chromosome combinations can be calculated or there is independent assortment of chromosomes.

On the basis of this parallel behaviour Sutton made the following conclusions:

1. At the conclusion of *meiosis,* the number of chromosomes going into each sperm or egg is just half of the number found in the cells of the parent. This corresponds to Mendel's statement that one and only one gene of each pair is present in a gamete.
2. The union of sperm (haploid) and egg (also haploid) with single set of chromosomes, re-establishes for the new organism the double set of chromosomes (diploid) present in the body cells of the parent organism. This corresponds to Mendel's requirement that the genes be contributed equally by each parent.
3. The individual chromosome retains its structure and identity throughout the various cell divisions of meiosis and later throughout the countless mitotic cell divisions. This preservation of the individuality of chromosome is comparable to the preservation of each gene throughout the generations of body cells and gametes.
4. During meiosis each pair of chromosome separates independently of every other pair. You may recall that this chromosome behaviour during meiosis is exactly parallel to the Principle of Independent assortment in Mendel's results.

On the basis of this parallel behaviour between genes and chromosomes, Sutton proposed chromosomal theory of heredity. According to this theory the genes are physical units located on the chromosomes. By this Sutton meant that one member of a gene pair is located on one homologous chromosome and the other member of a gene pair is located on the other homologous chromosome.

Although Sutton's work did not prove that the genes are carried on the chromosomes, it was a very important hypothesis in the understanding of genetics. The final proof that the genes are carried on the chromosomes was obtained through the work of the geneticist T.H. Morgan.

Sex Chromosomes

T.H. Morgan made great contribution to the understanding of genes and chromosomes. He won a Nobel Prize in 1933 for his work (fig. 10.1). One reason that Morgan's research was so successful was the choice of fruit fly (*Drosophila melanogaster*) as his experimental animal. It is often found hovering around rotten fruits. It is a very useful organism for genetic experiments.

Fig 10.1. T. H. Morgan (1866-1945)

Drosophila has only eight chromosomes. The cells in its salivary glands contain giant chromosomes which can be easily observed under the microscope.

In *Drosophila* cells, Morgan first noted a difference in the chromosomes of females and males. Female flies have four pairs of homologous chromosomes. But male flies have three pairs of homologous chromosomes plus a pair of chromosome in which two members are different from one another. One member in this pair is rod-shaped and is called, X chromosome. The other member is J-shaped and is called the Y chromosome. The female has two rod-shaped chromosomes called X chromosomes while a male has one X and one Y chromosome (Fig. 10.2).

As the X and Y chromosomes seem obviously related to sex they are, therefore, called **sex chromosomes**. The other chromosomes are called **autosomes**. Thus both female and male have three pairs of autosomes and one pair of sex chromosomes. A female normally has three pairs of autosomes

and two X chromosomes while the male has three pairs of autosomes and one X chromosome and a Y chromosome.

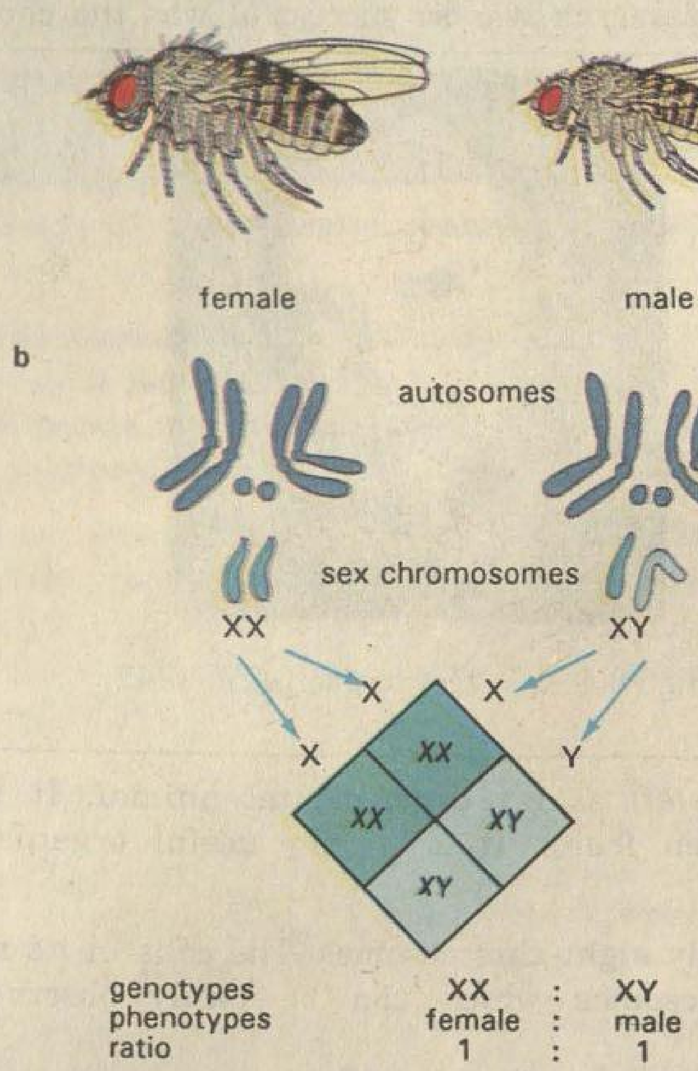

female
male
b
autosomes
sex chromosomes
XX
XY
X
X
X
Y
XX
XX
XY
XY
genotypes XX : XY
phenotypes female : male
ratio 1 : 1

Fig 10.2. Sex-Chromosomes in Drosophila

ex Determination in *Drosophila*

At the time of reproduction, male flies produce sperms, while females produce eggs. Eggs are of only one type and receive one X chromosome. There are, however, two types of sperms produced in the male flies. One type contains X chromosome and the other contains the Y chromosome. When fertilization occurs the zygote is either XX or XY depending on which type of sperm fertilized the egg. An XX zygote develops into a female and XY into a male. In Drosophila it is the sperm of male that determines the sex of the offspring (Fig. 10.3).

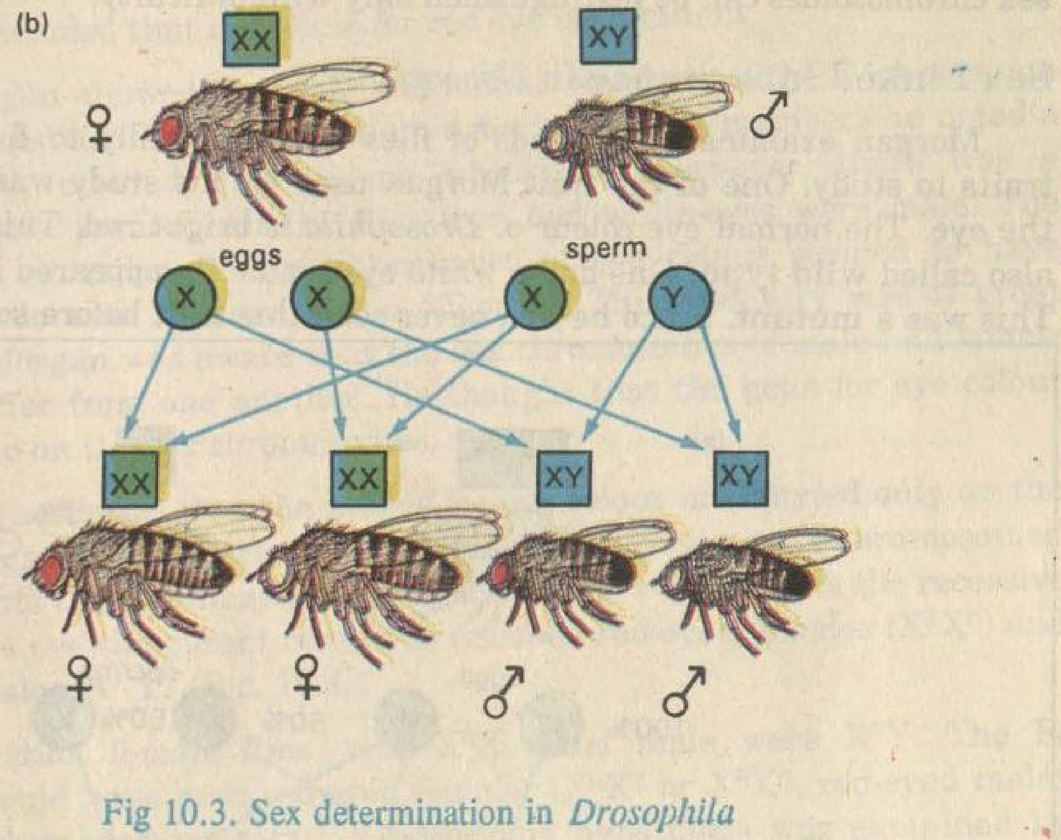


Fig 10.3. Sex determination in *Drosophila*

The pattern of sex determination shown in *Drosophila* is also present in many other organisms. In humans there are 23 pairs of chromosomes: 22 pairs are autosomes and one pair is sex chromosome. In humans all eggs contain one X chromosome in addition to 22 autosomes while the sperms produced are of two types i.e. the Y containing sperms and the X containing sperms.

Not all kinds of animals have sex determining sperms. In animals like birds, butterflies and moths it is the female that has XY type chromosomes. It produces two kinds of eggs X and Y. All sperms are alike because they carry X chromosome. It is the kind of egg cell that determines the sex of the organism. In still other species one of the sex chromosomes may be missing entirely. In some grasshoppers for example males have 23 chromosomes but females have 24. In this case half of the sperm cells have 11 chromosomes and the other half have 12. The sex of the young grasshopper depends on the kind of sperm that fertilizes the egg (work out how?)

In plants usually there are no individuals of separate sex. The same plant produces both male and female gametes. In plant species which have separate male and female individuals (e.g. liverworts, mosses & some flowering plants) sex chromosomes can be distinguished only with difficulty.

Sex Linked Inheritance in *Drosophila*

Morgan examined thousands of flies microscopically to find interesting traits to study. One of the trait Morgan used for his study was the colour of the eye. The normal eye colour of *Drosophila* is bright red. This type of fly is also called **wild type**. One day a white eyed male fly appeared in the culture. This was a **mutant**. Since he had never seen this trait before so he decided to

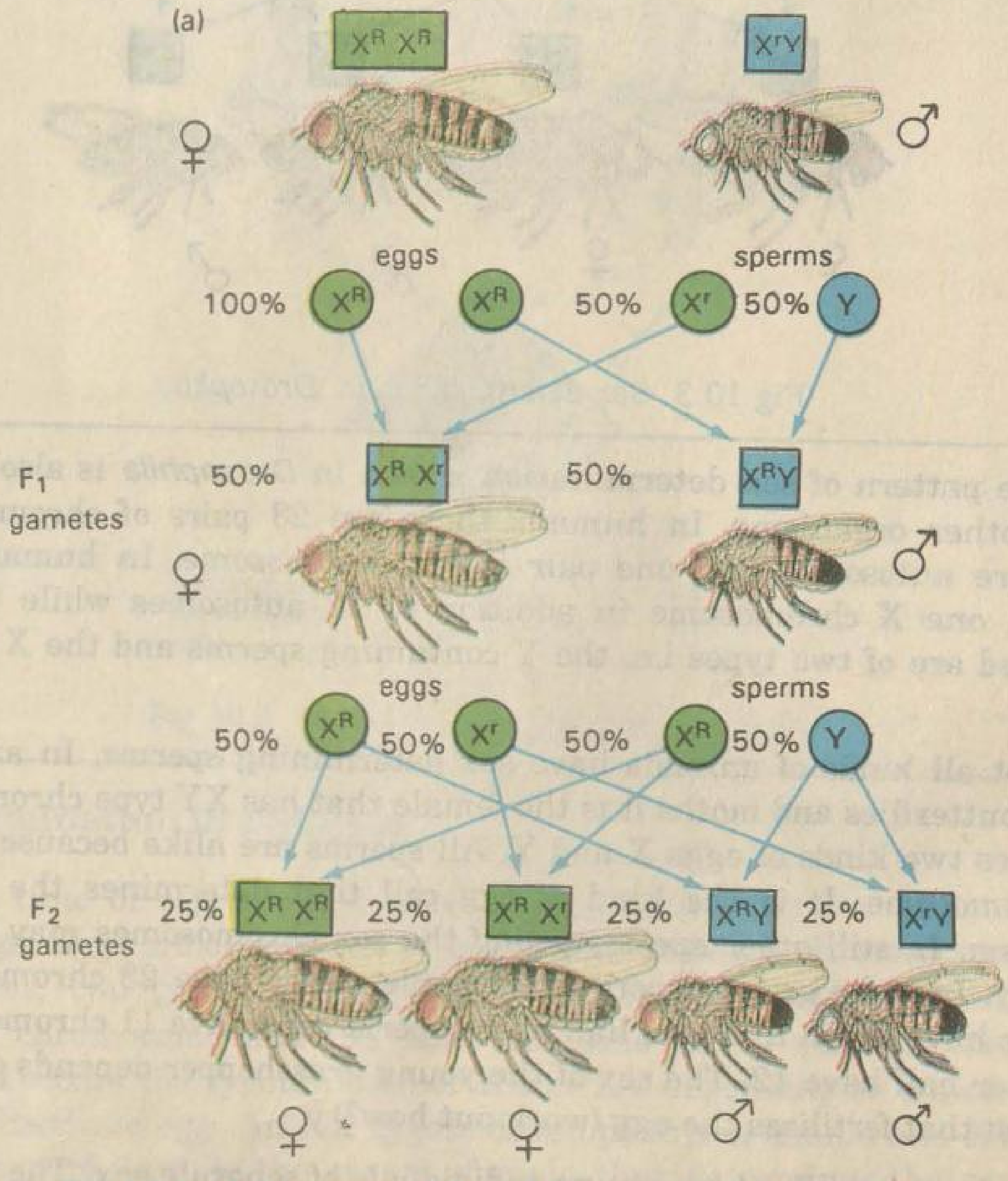

(a)
$X^R X^R$
X^rY
♀
♂
eggs
sperms
100%
X^R
X^R
50%
X^r
50%
Y
F_1 gametes
50%
$X^R X^r$
50%
X^RY
♀
♂
eggs
sperms
50%
X^R
50%
X^r
50%
X^R
50%
Y
F_2 gametes
25%
$X^R X^R$
25%
$X^R X^r$
25%
X^RY
25%
X^rY
♀
♀
♂
♂

Fig 10.4. Inheritance of the white-eye trait in Drosophila

study its inheritance pattern. His first step was to mate the white eyed male with a normal red eyed female. All offspring of this mating showed red eyes. So Morgan concluded that the allele for red eye is dominant.

Next Morgan allowed the male and female members of the F_1 generation to mate and produce the F_2 generation. Among these F_2 members he noted a ratio of three red-eyed flies to one white-eyed. However, there was a pecularity in the results. All the flies that had white-eyes were male. The females were all red-eyed. The inheritance of eye colour seemed to have something to do with the sex of the offspring. This discovery was of great importance. Morgan was aware that the sex chromosomes of male and female *Drosophila* differ from one another. He thought that the gene for eye colour may be located on the sex chromosomes.

His hypothesis was that the alleles for eye colour are carried only on the X chromosomes and there are no alleles for the eye colour on Y chromosomes. If 'R' represents the dominant gene for red eye and 'r' represents the recessive gene for white eye the parent cross was between red-eyed females (X^RX^R) and white-eyed males ($X^r Y$)' (Fig. 10.4).

F_1 generation female flies were X^RX^r and male were X^RY. The F_2 generation would have been red-eyed females (X^RX^R or X^RX^r), red-eyed males (X^RY), and white-eyed male ($X^r Y$). Morgans hypothesis was explained by showing how all males are white-eyed in the F_2 generation.

To find out more about what was happening, Morgan performed a kind of test cross. He mated the original white eyed male with a red-eyed female from the F_1 generation. This time half the female had white-eyes and half had red. Similarly half the male were red-eyed and the other half were white eyed (work out how?)

Once a white-eyed female had been obtained, it was possible to make a further confirming test. Morgan crossed a white-eyed female with a red-eyed male. All the females offsprings were red-eyed and all the males were white-eyed. When the F_1 white-eyed males and red-eyed females were mated, 50% of the females were red-eyed and other 50% of the females were white-eyed and 50% of the males were red-eyed and other 50% of the males were white-eyed as shown in the cross.

A trait that is controlled by a gene found on the X chromosome is a **sex-linked trait.** Most sex linked traits are determined by genes found on the X chromosome but not on Y chromosome. Morgan's discovery of sex-linked traits was a strong confirmation of Sutton's hypothesis that genes are located on sex chromosomes.

Sex Linked Inheritance in Man

There are numerous traits in humans that follow the same pattern of inheritance as is seen in the white-eyed trait of Drosophila. Two traits in humans can serve as examples i.e. colour blindness and haemophilia which are controlled by recessive genes designated as C and c and H and h respectively.

Colour Blindness

Colour blindness is a condition in which the individuals have difficulty in distinguishing red from green. Colour blindness can be detected by using special charts made up of coloured dots (fig. 10.5a). These dots are so arranged that colour blind person see a different pattern than do persons with normal

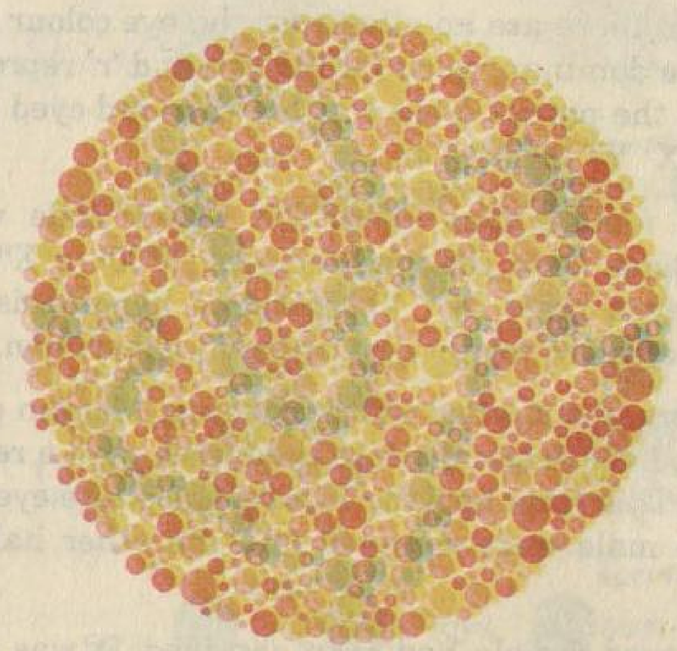


Fig. 10.5. a. Distinctively male. There are hundreds of sex-linked traits, all associated with the XY configuration. They appear in males but rarely in females. Red-green colour blindness is such a trait. People with this defect in vision will not be able to distinguish the green dots from red and so will not see the green path.

vision. Colour blindness is more common in males than in females. Relatively, few females suffer from colour blindness. It is not difficult to see why this is so. If a man receives an X chromosome that carries the gene for colour blindness from his mother , he will be colourblind. This is because there is no allele on the Y chromosome to offset the effect of the recessive gene for colour blindness on the X chromosome. But in order for a women to be colour blind, she should receive two x chromosomes which carry the genes for colour blindness, one from her mother and one from her father (Fig. 10.5b)

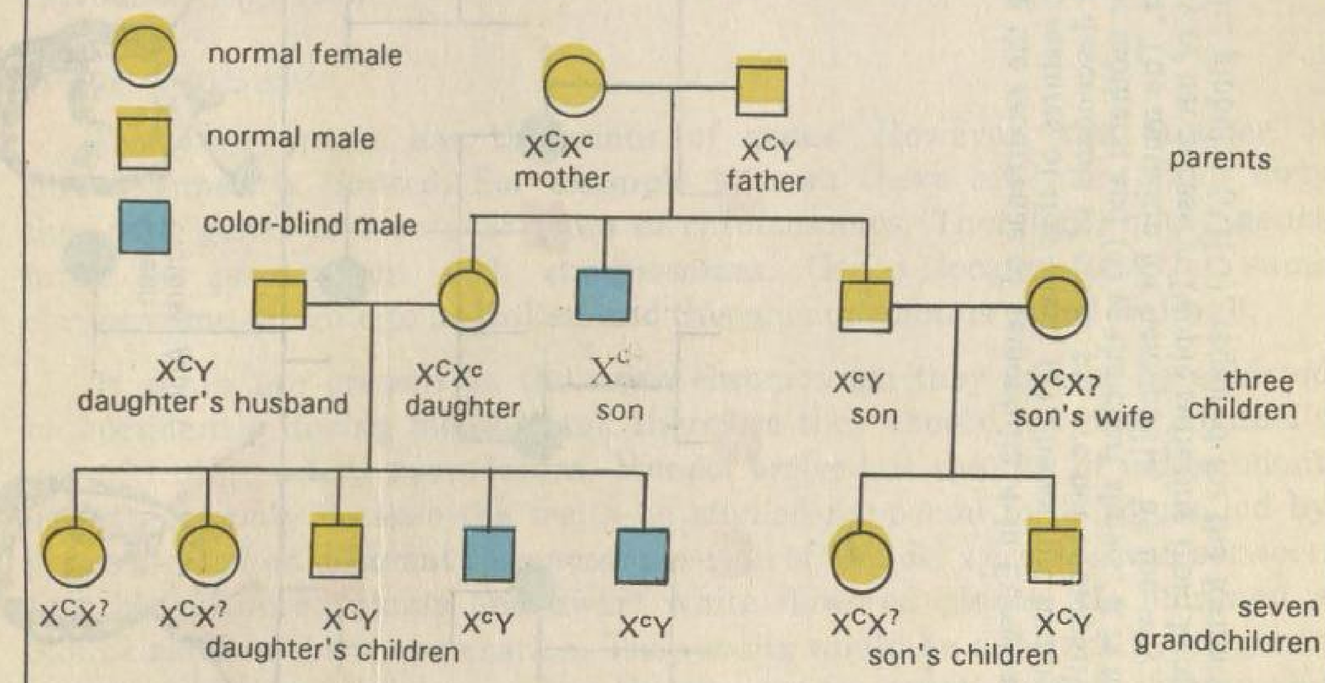

normal female
normal male
color-blind male
X^CX^c
mother
X^CY
father
parents
X^CY
daughter's husband
X^CX^c
daughter
X^c
son
X^cY
son
X^CX?
son's wife
three children
X^CX?
X^CX?
X^CY
X^cY
X^cY
daughter's children
X^CX?
X^CY
son's children
seven grandchildren

Fig. 10.5.b. Hypothetical Pedigree for the Inheritance of Color Blindness. In this three-generation pedigree for color blindness, the phenotypes and known genotypes are indicated. Assigning genotypes to the males is easy. Color-blind males have the color-blind allele (X^c) and normal-sighted males have the normal allele (X^C). Normal-sighted females may be either homozygous (X^CX^C) or heterozygous (X^CX^c). The latter are carriers of the color-blind allele, whose identity as such usually hinges on their giving birth to color-blind sons or to daughters who have color-blind sons. A female whose genotype is uncertain is indicated by $X^CX^?$.

Haemophilia

Haemophilia is a more serious genetic disease than colour blindness and fortunately a much rarer one. This is a condition in which the

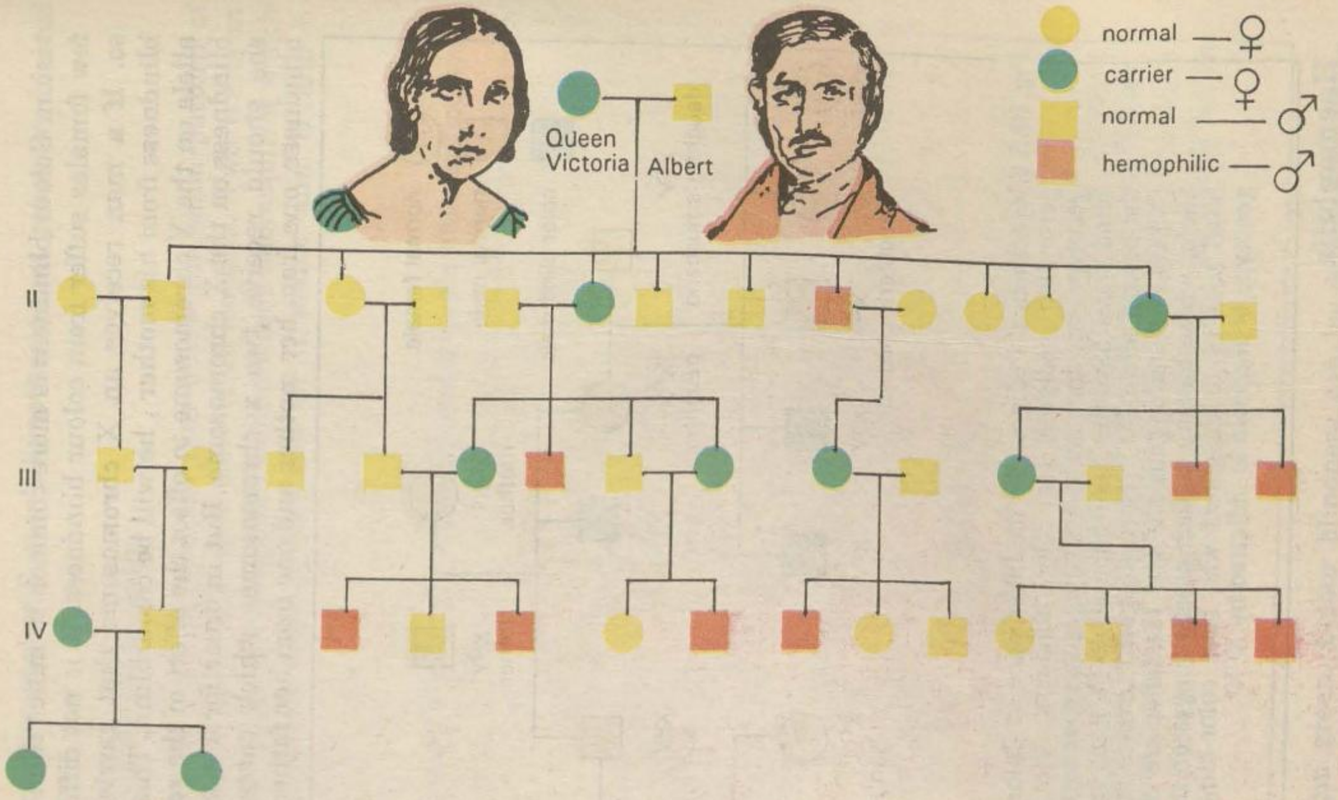


Fig 10.6. Pedigree chart showing the recurrence of hemophilia *A* in European royalty descended from Queen Victoria. Note several important features of this chart: (1) Phenotypic hemophiliacs appear to be limited exclusively to males; (2) Most of the descendants of either sex are not hemophiliacs; (3) Hemophilic sons appear to inherit the condition from their mothers; and (4) as the chart shows, it is the mothers, in all cases, who are the direct descendants of Victoria. The mutation for hemophilia, by the way, probably originated with Victoria, since it had not appeared in any of her ancestry. People suffering from hemophilia *A* cannot synthesize a blood protein known as antihemophilic globulin (AHG), required for the formation of thromboplastin, and thus for normal blood clotting.

blood fails to clot after an injury or clots very slowly. Persons with extreme cases of haemophilia can bleed to death from small cuts or bruises. Like colour blindness incidence of haemophilia is also less frequent in women as compared to men.

This is because a female receives one X chromosome from her mother and the other from her father. For a women to have haemophilia both of the X chromosomes have to carry the recessive haemophilia gene. This occurs very rarely, partly because few haemophiliacs male survive to marry and reproduce (Fig. 10.6).

Gene Linkage

Every organism has thousands of genes. However, the number of chromosomes is limited. For example in man there are more than forty thousand genes and only 23 pairs of chromosomes. Therefore, many genes must be present on each chromosomes. Genes located on the same chromosome are said to be **linked** and this phenomenon is called **linkage**.

If genes are present on the same chromosome they cannot be assorted independently during meiosis, and therefore they should not obey Mendel's law of **independent assortment.** Mendel arrived at the law of independent assortment only because the traits he studied happened to be controlled by genes located on different chromosomes. One of Mendel's crosses was between tall, red flowered plants and dwarf white flowered plants. He obtained a 9:3:3:1 ratio in the F_2 generation. The results would be different if the genes were linked. Gene linkage reduces the chances for genetic recombination and variety among offspring.

Crossing Over

If all linked genes in a population remained in their parental combinations, the variety among organisms would be limited. Geneticists have come to realize that linked genes can be separated by a process called **crossing over**. Crossing over is an exchange of segments of chromatids of homologous chromosomes in meiosis (Fig.10.7). Crossing over may occur at more than one places along a chromosome. To understand the mechanism of crossing over during meiosis consider a cell consisting of only one pair of homologous chromosomes (Fig. 10.7.) During the early stages of meiosis the pairing of chromosomes takes place. At this stage each chromosome consists of two chromatids. During the pairing or synapsis exchange of segments of homologous chromosomes or crossing over takes place. The next effect of this crossing over is that there is an exchange of hereditary material and the resulting haploid gametes contain four different types of chromosomes. If crossing over did not occur the gametes would be only of two types A B and ab. However, with crossing over four types of gametes are produced = AB, Ab, aB, and ab. It has a survival value for a population. Most gametes will have parental combinations of linked genes but some are different as a result of crossing over. These gametes are called **recombination gametes.** The union of these gametes with other gametes results in offspring with a wider variety of traits which helps a population survive over long period of time in a changing environment.

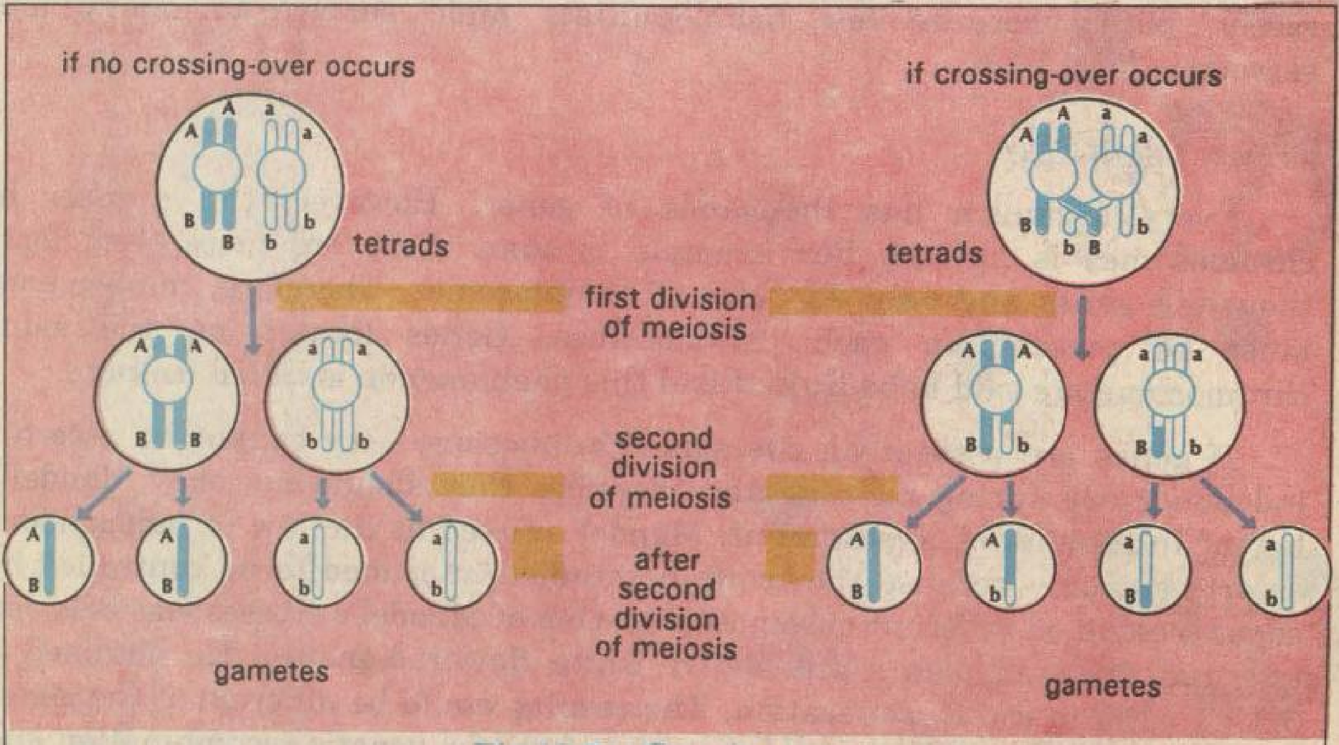

if no crossing-over occurs
if crossing-over occurs
A
a
B
b
tetrads
tetrads
first division of meiosis
second division of meiosis
after second division of meiosis
gametes
gametes

Fig 10.7. Crossing over

Abnormal Chromosome Numbers

Meiosis is a very complex and intricate process. The separation of homologous chromosomes must occur without mistake if completely normal gametes are to be formed. But it is not surprising that mistakes do occur. One of the most common error in meiosis is a phenomenon called **nondisjunction.** This is the failure of a pair of homologous chromosomes to detach and segregate from one another (Fig. 10.8)

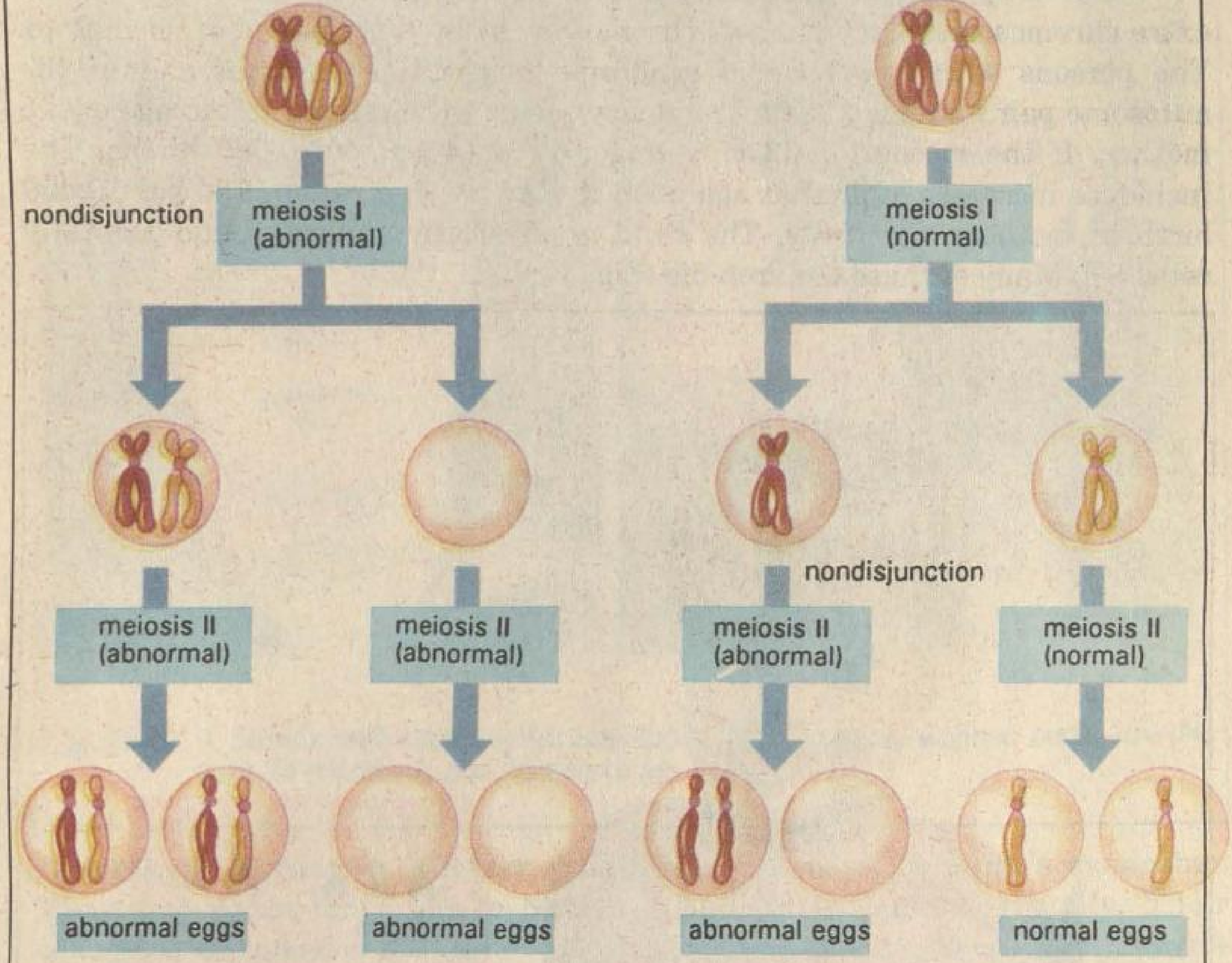

nondisjunction
meiosis I
(abnormal)
meiosis I
(normal)
meiosis II
(abnormal)
meiosis II
(abnormal)
nondisjunction
meiosis II
(abnormal)
meiosis II
(normal)
abnormal eggs
abnormal eggs
abnormal eggs
normal eggs

Fig 10.8. Nondisjunction results from an error in meiosis in which homologous chromosomes fail to separate during meiosis I. Nondisjunction can also occur during meiosis II when two sister chromatids fail to separate.

This results in gametes that are either missing a chromosome or have an extra chromosome in their nuclei. If such a gamete unites with a normal gamete, the resulting zygote will have the chromosome abnormality. Thus an extra chromosome may be present in the new organism $(2n+1)$ or an entire chromosome may be omitted $(2n-1)$.

Nondisjunction causes several serious genetic defects in humans. Some of these genetic defects in humans are **Down's syndrome, Turner's syndrome and Klinefelter's syndrome.**

Down's syndrome commonly known as **mongolism** is the result of an extra chromosome. They have 47 chromosomes (2n + 1) instead of normal 46. The persons with this form of syndrome have three chromosomes of the autosome pair number 21. The frequency seems to be related to the age of the mother. If the mother is 32 or younger it is 14 out of 10,000 births. The incidence increases after that age until it may reach a rate of 150 per 10,000 birth in mothers over forty. The child is physically abnormal and mentally retarded. Many of these children die (Fig. 10.9).

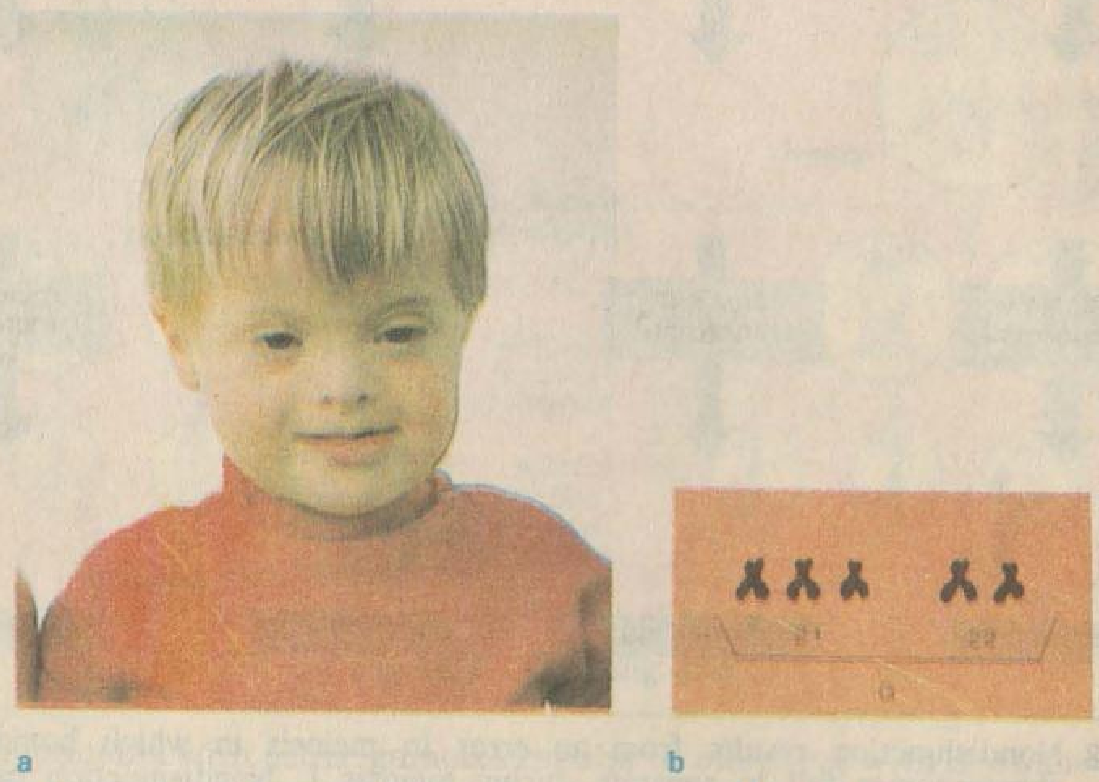


Fig 10.9. The classical eye and facial features of a child with Down's syndrome (a) are due to (b) the presence of three number 21 chromosome among the chromosomes designated by the letter G.

Turner's syndrome Another rare disorder of human females is called Turner's syndrome. Females with this syndrome have only 45 chromosomes (2n-1) instead of normal 46. Instead of XX chromosomes they have only one X chromosome. The other X chromosome is missing. This syndrome is less common and occurs in about four out of 10,000 births. The individual suffers from Turner's syndrome never becomes sexually mature. (fig. 10.10).

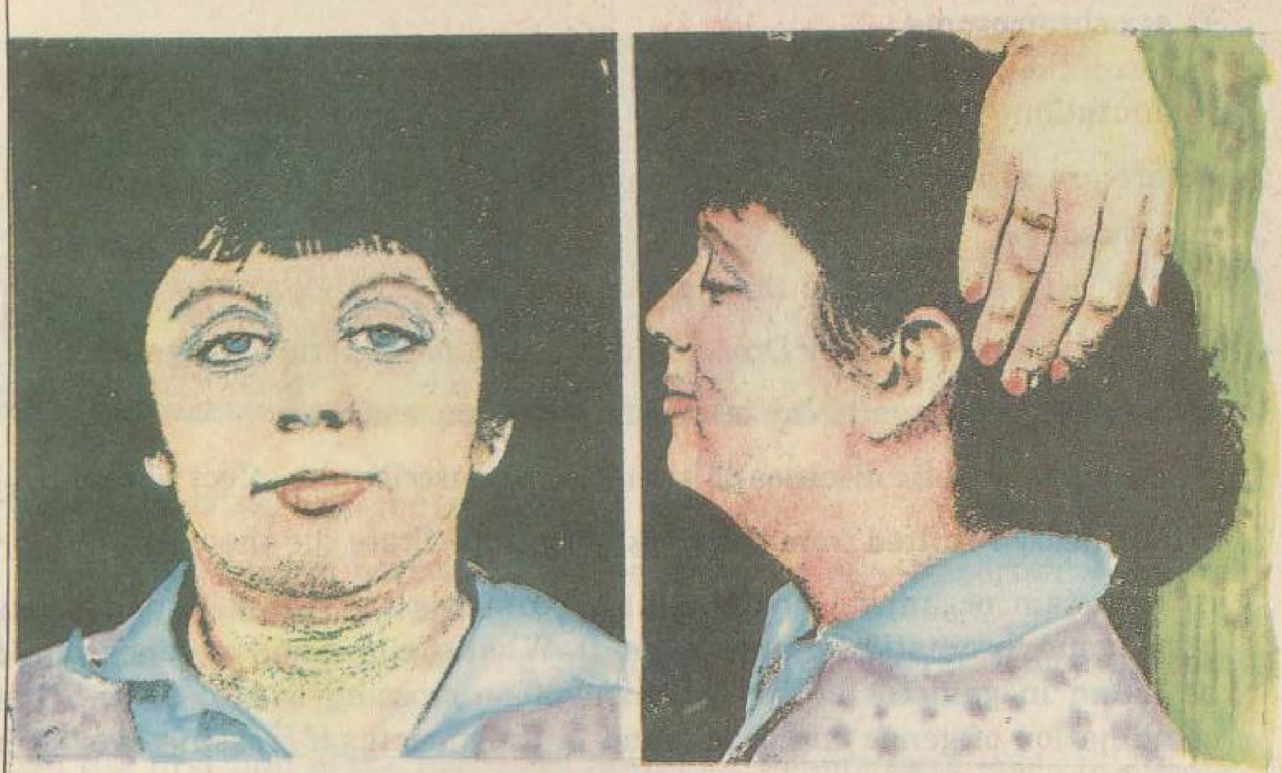


Fig 10.10. A female with turner syndrome shows short stature, webbed neck, low-set ears, broad chest, and immature sex organs.

Klinefelter's syndrome. Another syndrome is called Klinefelter's syndrome. These are males that grow to be adults but fail to mature sexually. Their chromosome count is 47 (2n + 1). This is the same number as in Down's syndrome. However the male has an extra sex chromosome. In this case, the sex chromosomes are X X Y. This syndrome occurs in about 10 of every 10,000 births. Females who have three X chromosomes occur rarely. Although they are usually fertile and physically normal, they often are mentally retarded. Males with two Y chromosomes (X Y Y) also occur and have criminal tendency.

QUESTIONS

1. Define the following terms:
   a) autosome
   b) crossing over
   c) colour blindness
   d) gene linkage
   e) nondisjunction

   f) sex-chromosome
   g) sex-linked trait
   h) mutation

2. Where are genes located? Describe parallel behaviour between genes and chromosomes.
3. How is sex determined in Drosophila, birds and grasshopper?
4. Give several reasons why Drosophila is useful for genetic experiments.
5. What is crossing over? Why is crossing over important?
6. Name three genetic diseases of humans and describe the effect of each.
7. What theory resulted from the work of Sutton? State the theory.
8. In a certain organism, one chromatid contains the genes A and b. Its homolgous chromatid contains a and B. What combination of genes would be found in gametes of the organism if no crossing over occurs. What combination of genes might be found in the gametes if crossing over does occur?
9. In humans, why is colour blindness more common in male than females?
10. In Drosophila, the gene for red-eye, 'R' is dominant to the gene for white eye, r. This trait is sex-linked. Determine the probable genotypic an phenotypic ratios expected from a cross between (a) a heterozygous femal and red-eyed male, (b) a heterozygous female and a white-eyed male, (c) homozygous dominant female and are red-eyed male and (d) homozygous red-eyed female and a red-eyed male.
11. If a normal man marries a normal woman whose father is colour blind what are the chances that either sons and daughters will be colour blind?
12. What will be the number of autosomes in an organism with 33 pairs of chromosomes?

THE HEREDITARY MATERIAL

11

Chemical Basis of Heredity

Mendel's work on heredity is considered to be very important. However, this work did not reveal much about the nature of genes or the mechanism by which genes exert control over the growth, development of characteristics and functional aspects of living things.

In the first half of the twentieth century attempts were made to discover the chemical basis of heredity. All investigations supplied conclusive evidence that chromosomes are composed of DNA and protein. The big question now was whether DNA or protein is the hereditary material or whether both are responsible for inheritance.

Swiss biochemist Friedrich, Miescher (1869) isolated a material from the nuclei of fish sperms that he called **nuclein** which was later named as **nucleic acid** because of its acidic nature. Later research found that nucleic acids are of two types, namely (1) deoxyribonucleic acid or DNA and (2) ribonucleic acid or RNA. DNA occurs only in the nuclei of the cells while RNA is found mainly in the cytoplasm.

It was not until 1944 that it became clear that the hereditary material must be DNA, and not protein. To understand this, you may recall from previous chapters the transformation experiments performed by Frederick Griffith in 1928. He injected heat killed smooth cells of pneumococcus (originally virulent but now killed by heat) alongwith live rough cells (originally non-virulent, and alive) into healthy mice, he expected the mice to remain healthy. This is because the smooth cells were dead. However, some of the mice died of pneumonia. On examining the blood of the dead mice, Griffith found living smooth type bacteria from the dead mice. From this experiment Griffith concluded that some factor from dead smooth type bacteria has transformed rough type bacteria into smooth type bacteria.

Avery, Macleod and McCarty (1944) identified the transforming material in Griffith's experiment as DNA. They showed that DNA isolated from heat killed smooth bacteria could transform alive rough bacteria (non-virulent) into virulent strain, which would kill mice. The conclusive evidence on DNA as the genetic material was provided by Hershey and Chase in 1952. They made use of viruses which are called bacteriophagess. Bacteriophage or phage virus that infects bacteria. It consists of a DNA core surrounded by a protein coat (Fig. 11.1)

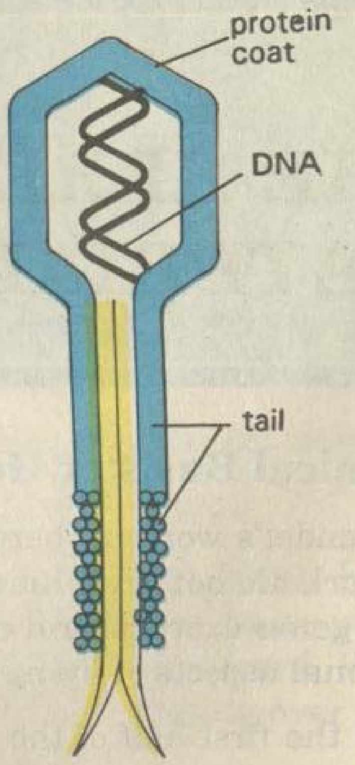


Fig 11.1. Structure of a Bacteriophage

A phage attacks a bacterium entering and producing hundreds of new phage particles inside the bacterial cell. The cell then ruptures and the new phage particles are released. These can in turn attack other bacterial cells. What Hershey and Chase wanted to find out was whether the whole phage entered the bacterium, or was it just the DNA or the protein. They decided to label the protein and DNA of the phage particles with different radioactive elements in the hope of answering this question.

DNA contains phosphorus in its chemical composition but no sulphur. Virus protein contains sulphur but no phosphorus. Hershey and Chase devised a way to label the phage DNA with radioactive phosphorus (p^{32}) and the protein coat with radioactive sulphur (S^{35}). One bacterial culture was then exposed to phage with radioactive DNA and the other culture was exposed to phage with radioactive protein.

After a large number of bacterial cells had become infected with phages, the cells were separated from the medium and their contents tested for radioactivity. The cells that had been infected by phages with radioactive

DNA showed a large amount of radioactivity. The cell infected by phages with radioactive protein showed almost no radioactivity (Fig. 11.2).

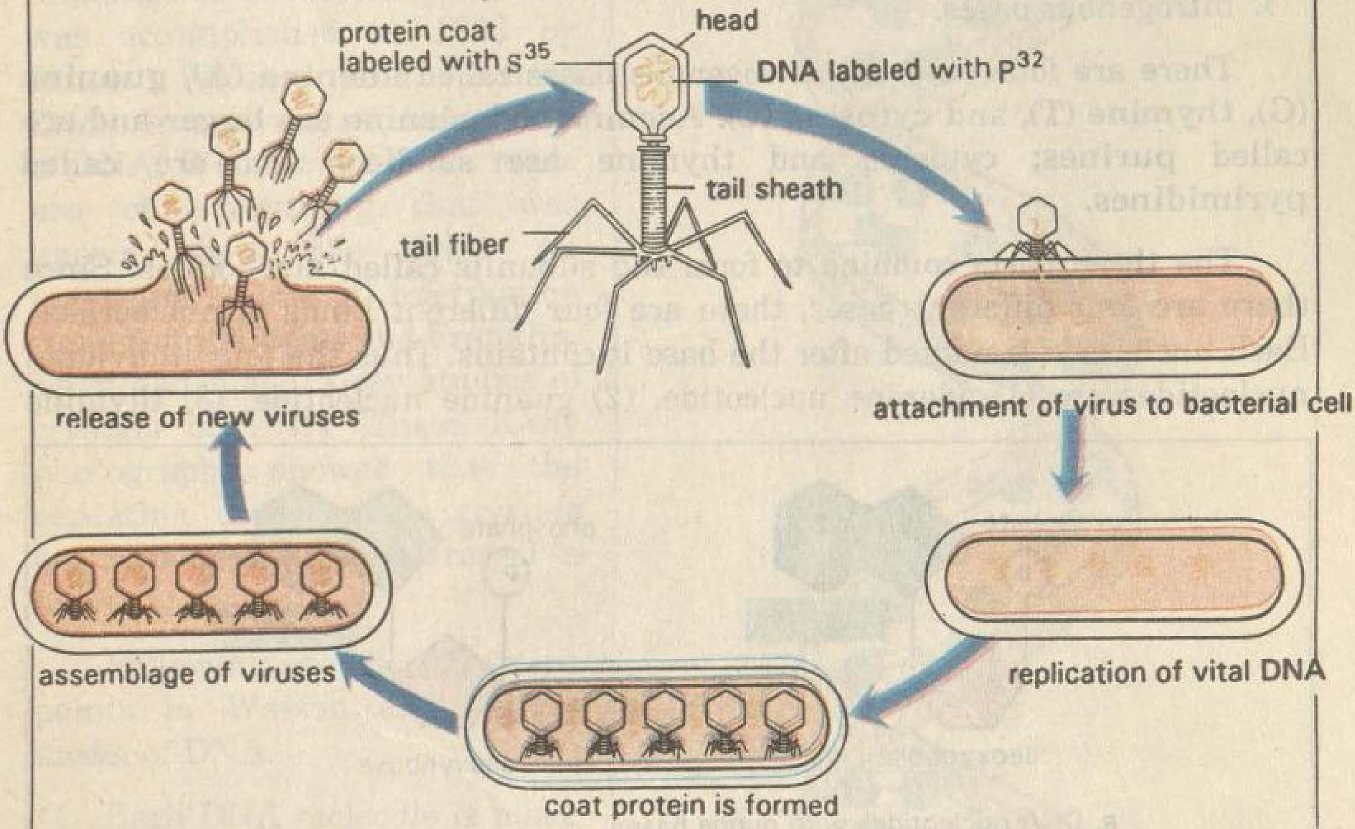

protein coat
labeled with S^{35}
head
DNA labeled with P^{32}
tail sheath
tail fiber
release of new viruses
attachment of virus to bacterial cell
assemblage of viruses
replication of vital DNA
coat protein is formed

Fig 11.2. The Hershey-Chase experiment

This experiment proved that when phage infects bacteria, only the phage DNA enters the cells and the phage protein remains out side. This belief was confirmed by studies with electron microscope. It was found that when phage attaches to the wall of the bacterial cell, the protein coat remains outside, and the DNA core passes into the bacterial cell.

The results of the Hershey and Chase's experiment, therefore, provided good evidence that DNA is infact the hereditary material. The next step was to find the chemical structure and function of DNA.

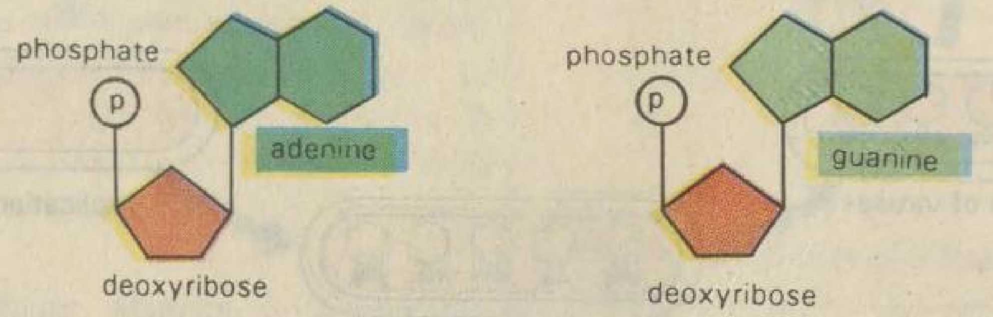
Chemical Composition of DNA

DNA is a complex molecule, consisting of a polynucleotide chain. This chain comprises of several units known as **nucleotides**. Each nucleotide is made up of three chemical components.

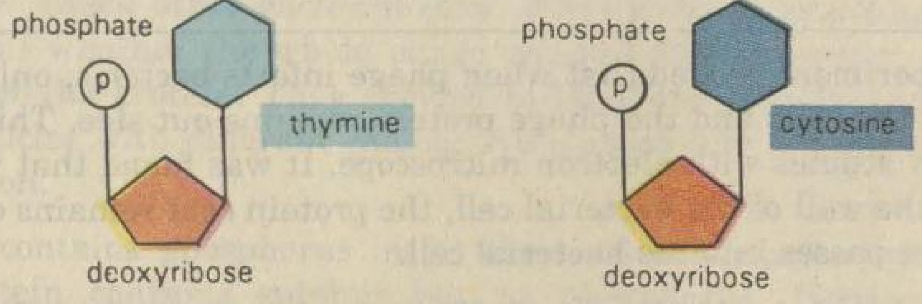
1. 5-Carbon sugar called deoxyribose,
2. a phosphate group, and
3. nitrogenous bases.

There are four different nitrogenous bases called **adenine (A), guanine (G), thymine (T),** and **cytosine (C).** Adenine and guanine are larger and are called **purines;** cytosine and thymine are smaller, and are called **pyrimidines.**

The three parts combine to form the subunits called nucleotides. Since there are four different bases, there are four different kinds of nucleotides. Each nucleotide is named after the base it contains. Thus the four individual nucleotides are (1) adenine nucleotide, (2) guanine nucleotide, (3) thymine nucleotide, and (4) cytosine nucleotide. Many nucleotides join together to form a DNA molecule (Fig. 11.3).


phosphate
p
adenine
deoxyribose
phosphate
p
guanine
deoxyribose

a. DNA nucleotides with purine bases


phosphate
p
thymine
deoxyribose
phosphate
p
cytosine
deoxyribose

b. DNA nucleotide with pyrimidine bases

Fig 11.3. Formulae of nucleotides

Structure of DNA

After the chemical composition of DNA was known, the structure of the molecule remained to be worked out. This was accomplished in 1953 by James Watson and Francis Crick. In arriving at their model of DNA, Watson and Crick made use of everything that was known about the DNA. An important piece of information came from Wilkins and Franklin. They had made X-ray studies of crystals of DNA. These X-ray photographs showed that the repeating units in the crystals are arranged in the form of a helix.

Following are the important points in Watson and Crick's model of DNA.

1. Each DNA molecule is made up of two strands which are twisted around one another to form a double helix. The double helix looks like a ladder as shown in Fig.11.4.

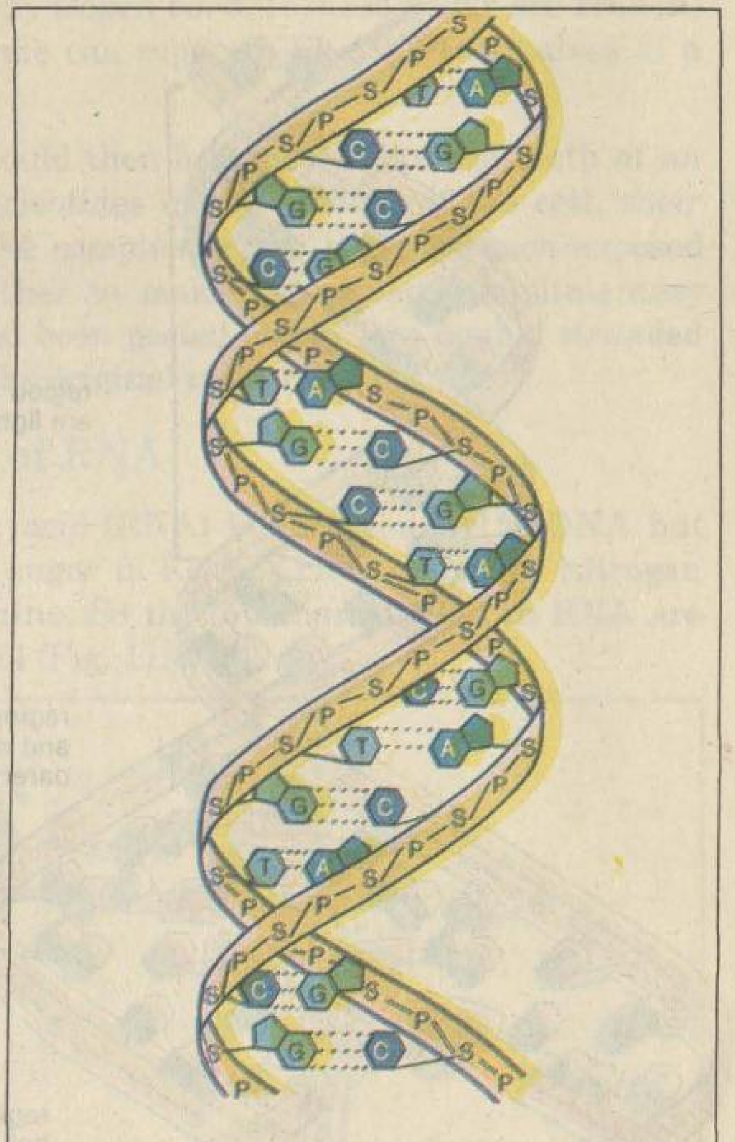
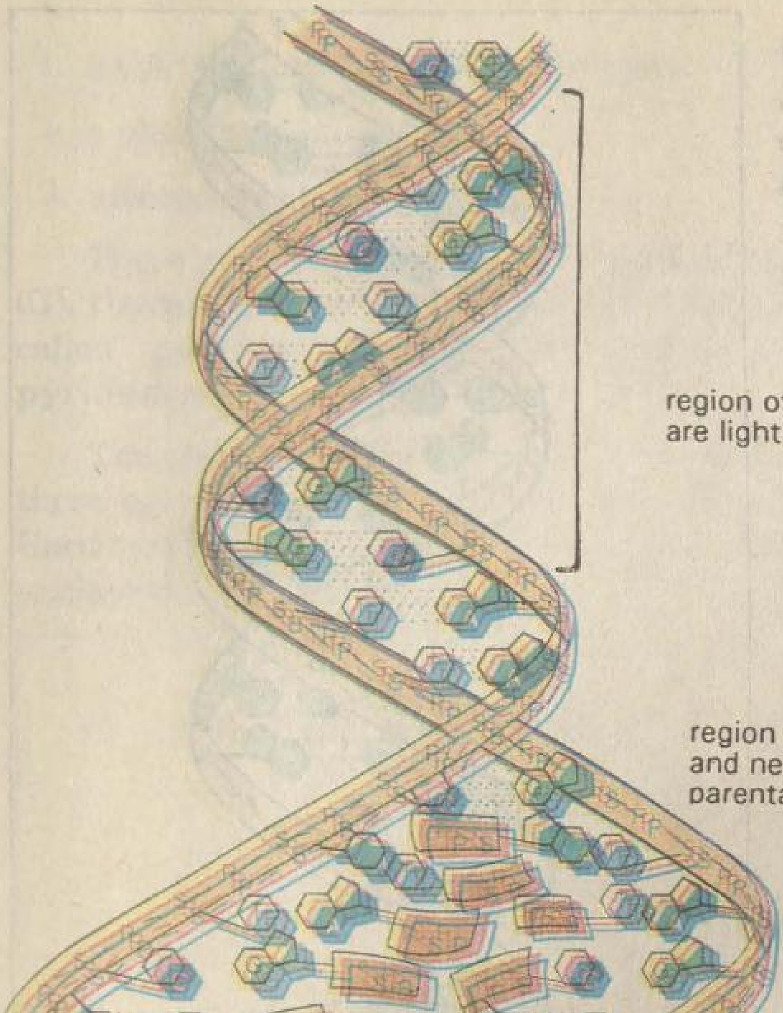


Fig 11.4. Watson and Crick model of DNA

2. The two strands are held together by weak hydrogen bonds. As shown in the above figure, two hydrogen bonds are formed between A and T and three hydrogen bonds are formed between C and G.

Replication of DNA

Long before the discovery of DNA structure, biologist knew that the genetic information present in DNA had to be duplicated prior to cell division. Thus the hereditary material or DNA had to be capable of self replication. Waston and Crick model of DNA tells us how this replication of DNA molecule can occur (Fig. 11.5). The base pair that form the rungs of the model



region of parental DNA helix. (both backbones are light).

region of replication. parental DNA is unzipped and new nucleotides are pairing with those in parental strands.

region of completed replication. Each double helix is composed of an old parental strand (light) and a new daughter strand (dark). Notice that each double helix is exactly like the other one.

Fig 11.5. Replication of DNA

are held together by a weak type of hydrogen bond. If these bonds are broken, the two strands of the DNA molecule can separate like the two halves of a zipper

The bases along each strand would then be exposed like the teeth of an opened zipper. If there are free nucleotides in the nucleus of the cell, their bases could be attracted towards the complementary bases on each exposed strand. They could then join together to make a complete complimentary strand exactly like the one that had been peeled away. Two double stranded molecules of DNA are exactly like the original molecule.

Composition and Structure of RNA

The composition of ribonucleic acid (RNA) is very similar to DNA but with two differences. The 5-Carbon sugar in RNA is **ribose** and the nitrogen base **uracil** is substituted for **thymine**. So the four bases found in RNA are adenine, guanine, cytosine and uracil (Fig. 11.6).

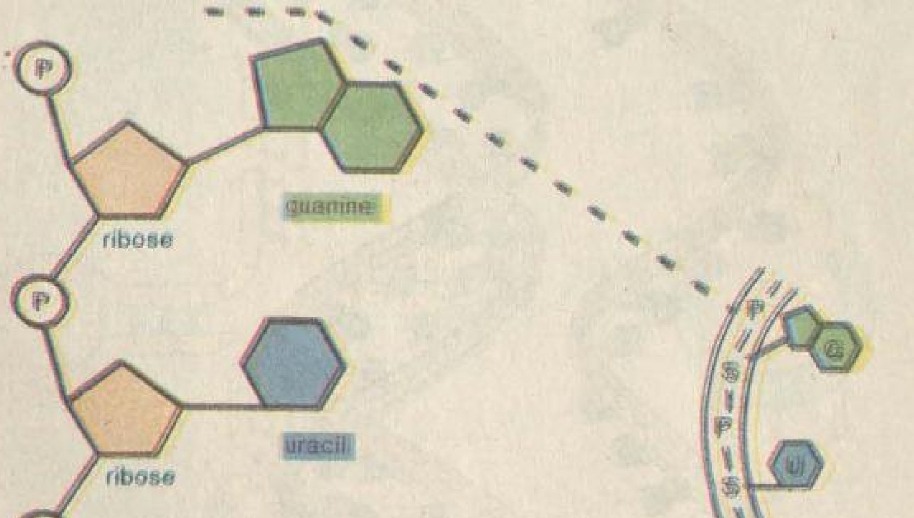


Fig 11.6. Structure of RNA

Different Types of RNA

There are three types of RNAs i.e. messenger RNA (mRNA) **transfer**

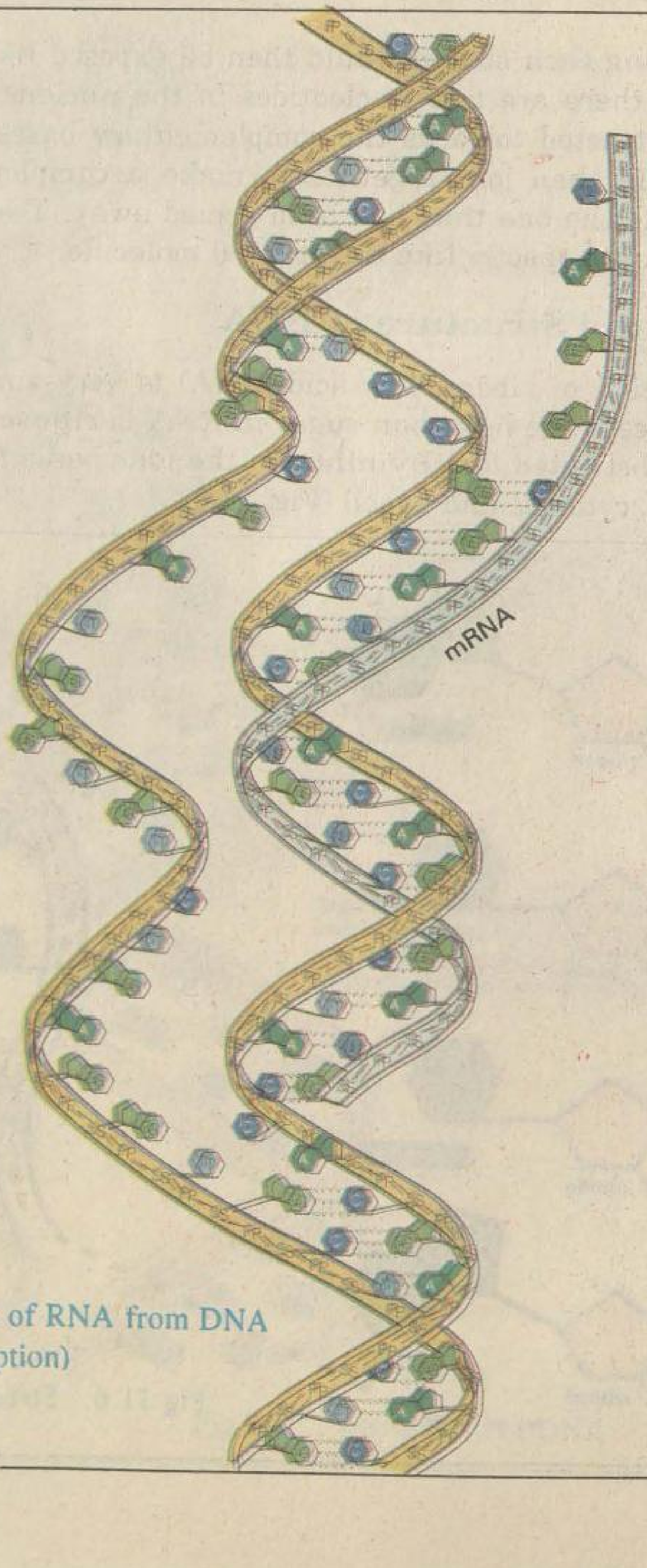


Fig 11.7. Synthesis of RNA from DNA (Transcription)

RNA (tRNA) and **ribosomal** RNA (rRNA). The messenger RNA is the direct copy of DNA. The first step in converting the code into a polypeptide is to copy the message for the polypeptide into a molecule of RNA. To copy the code, the DNA strand separates and serves as a template for RNA (Fig. 11.7).

Complimentary RNA nucleotides take their places along the exposed strands, in the same way as in DNA strand. The RNA strand is now a separate molecule carrying the complete message for a single polypeptide. This message is in the complimentary form, i.e. each A of DNA is represented by a U each T by an A, each G by a C and each C by a G. A strand of RNA of this type is called messenger RNA. The copying of genetic message into a molecule of mRNA is called **transcription**. Each group of three bases that specifies an amino acid is called as **codon.**

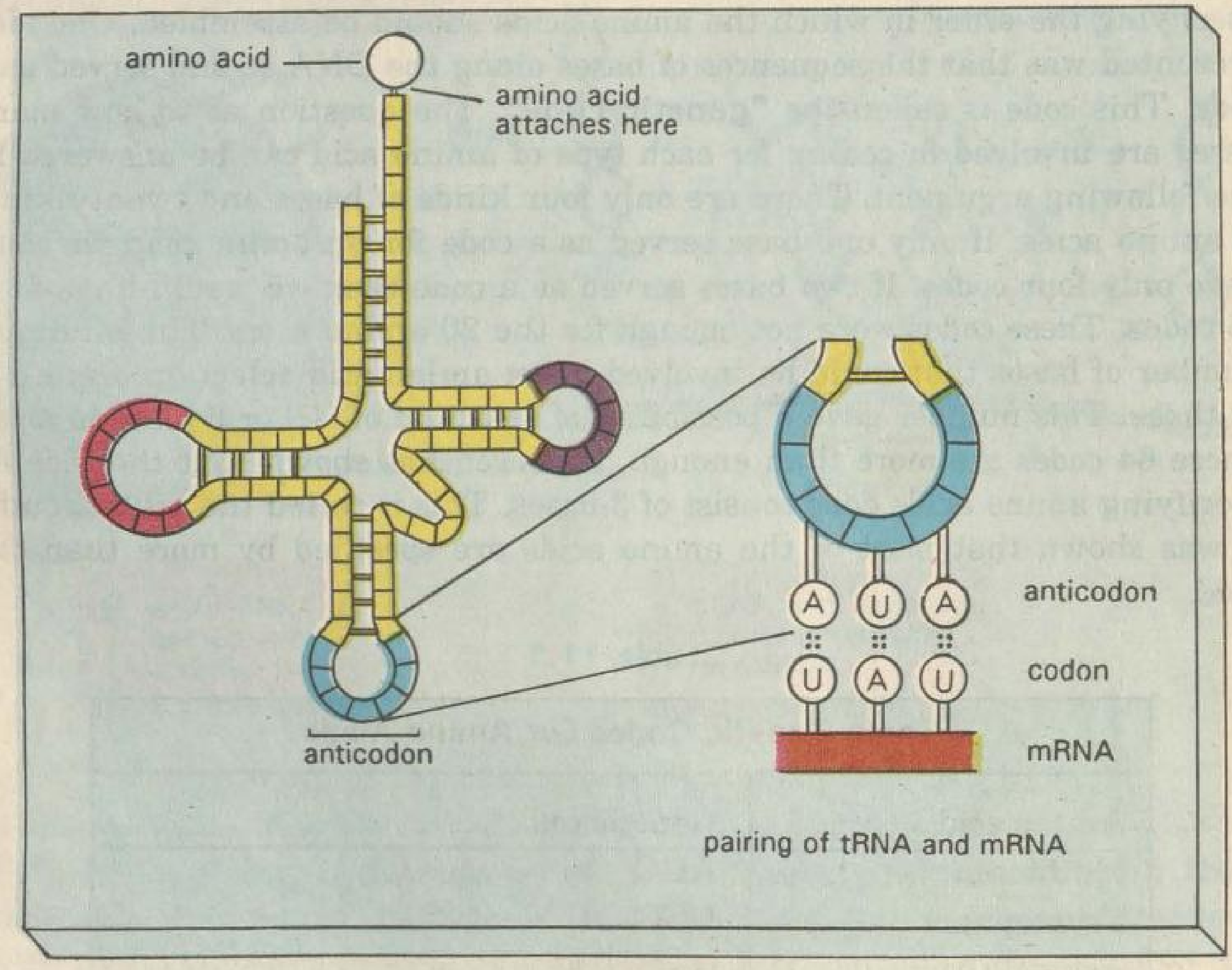


Fig 11.8. Clover leaf model of transfer RNA

Messenger RNA is only one of the three types of RNA that are formed by DNA. A second type of RNA formed by DNA is called transfer RNA or tRNA.

It is clover shaped and binds with specific amino acids. For twenty different amino acids, there are twenty different types of tRNA (Fig. 11.8).

Each tRNA has sequence of three bases, called anticodon, which is complimentary to codon of mRNA. Thus tRNA is a device for bringing a particular amino acid to a particular place specified by mRNA.

Ribosomal RNA, is formed by DNA and is one of the major components of ribosomes.

Nucleic Acid and Genetic Code

At the time when Watson and Crick's model of DNA was accepted, it was generally agreed that each gene directs the synthesis of a particular polypeptide chain of amino acids. Therefore, the gene must have some way of specifying the order in which the amino acids should be assembled. One idea presented was that the sequences of bases along the DNA strand served as a code. This code is called the **"genetic code"**. The question as to how many bases are involved in coding for each type of amino acid can be answered by the following argument. There are only four kinds of bases and twenty kinds of amino acids. If only one base served as a code for an amino acid we could have only four codes. If two bases served as a code then we would have 4^2 or 16 codes. These codes were not enough for the 20 amino acids. The minimum number of bases that could be involved in an amino acid selection seemed to be three. This number gave a possibility of selection of (4^3) or 64 amino acids. These 64 codes are more than enough. Research has shown that the code for specifying amino acids does consist of 3-bases. This is called the **triplet code.** It was shown that most of the amino acids are specified by more than one code.

Table 11.1

Some Genetic Codes For Amino Acids

Amino acid	Genetic code
Methionine	AUG
Tryptophan	UGG
Aspartic acid	GAU, GAC
Isoleucine	AUU, AUC, AUA
Alanine	GCU, GCC, GCA, GCG
Arginine	CGU, CGC, CGA, CGG, AGA, AGG

Protein Synthesis

The three kinds of RNAs as well as the ribosomes are synthesized inside the cell nucleus. They later migrate to the cytoplasm through nuclear pore. In the cytoplasm there is a supply of all the amino acids needed to synthesize the cell's proteins. Here, the synthesis of protein takes place according to the instructions present in mRNA. In the cytoplasm, amino acid molecules become attached to their specific type of tRNA. Ribosomes become attached to each strand of mRNA at intervals along its length. At the place where ribosome is attached to mRNA, a molecule of tRNA with the right anticodon temporarily becomes attached to the corresponding codon on the mRNA (Fig.11.9). The amino acid brought into position by tRNA joins the last amino

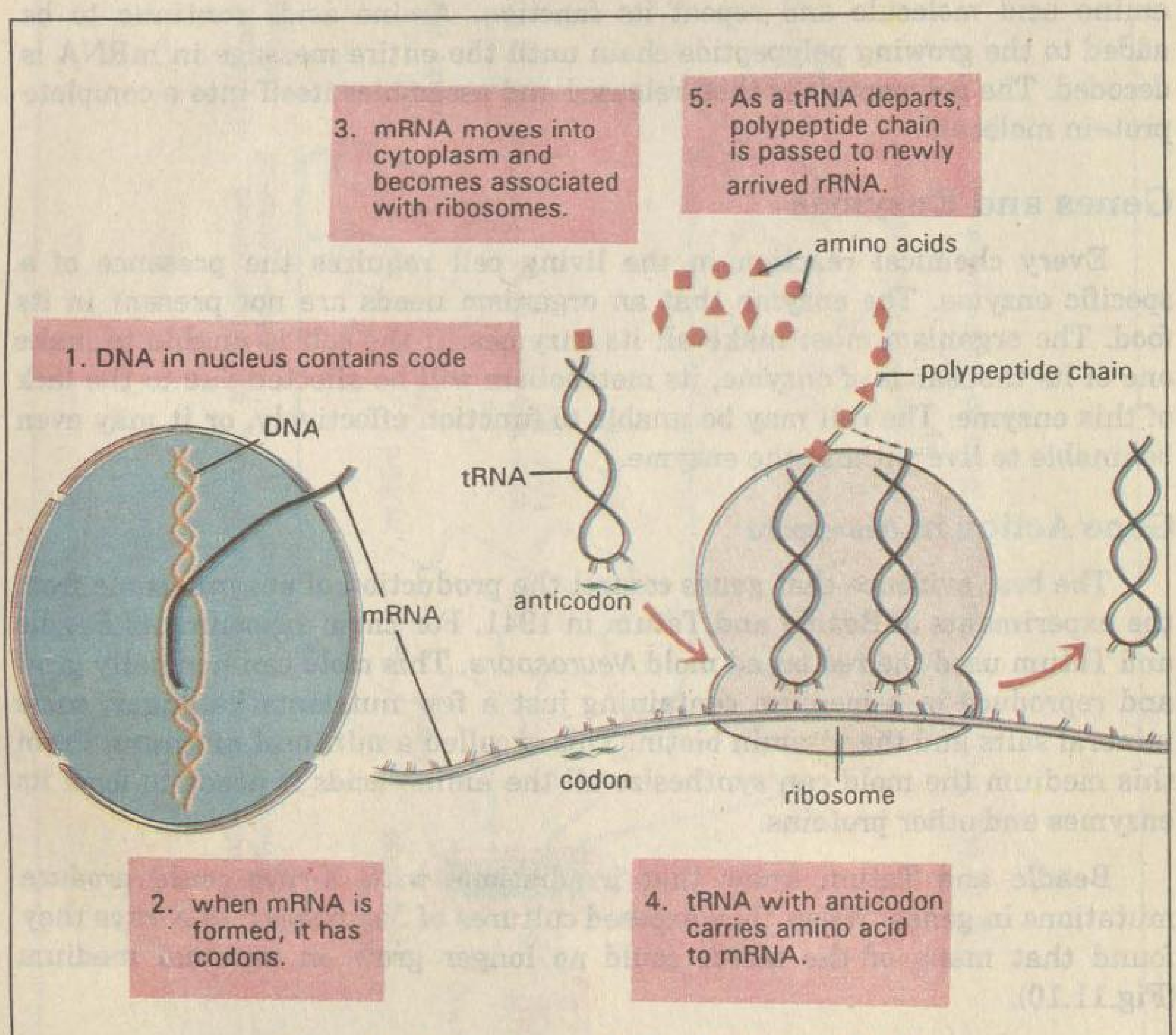

3. mRNA moves into cytoplasm and becomes associated with ribosomes.
5. As a tRNA departs, polypeptide chain is passed to newly arrived rRNA.
amino acids
1. DNA in nucleus contains code
polypeptide chain
DNA
tRNA
anticodon
mRNA
codon
ribosome
2. when mRNA is formed, it has codons.
4. tRNA with anticodon carries amino acid to mRNA.

Fig 11.9. Various steps during Protein synthesis

acid in forming the chain and separates from tRNA. The ribosome then moves along the next codon. A new tRNA takes its place on the mRNA strand and its amino acid joins the polypeptide chain. As the ribosomes moves along the tRNA that has served its purpose is released. It is now free to pick up another amino acid molecule and repeat its function. Amino acids continue to be added to the growing polypeptide chain until the entire message in mRNA is decoded. The polypeptide is then released and assembles itself into a complete protein molecule.

Genes and Enzymes

Every chemical reaction in the living cell requires the presence of a specific enzyme. The enzyme that an organism needs are not present in its food. The organism must make all its enzymes. If the cell is unable to make one of its thousands of enzyme, its metabolism will be affected due to the lack of this enzyme. The cell may be unable to function effectively, or it may even be unable to live without the enzyme.

Gene Action in *Neurospora*

The best evidence that genes control the production of enzyme came from the experiments of Beadle and Tatum in 1941. For their experiments Beadle and Tatum used the red bread mold *Neurospora*. This mold can normally grow and reproduce in a medium containing just a few nutrients i.e. sugar, some mineral salts and the vitamin biotin. This is called a **minimal medium.** From this medium the mold can synthesize all the amino acids it needs to form its enzymes and other proteins.

Beadle and Tatum knew that irradiations with X-rays could produce mutations in genes. When they exposed cultures of *Neurospora* to X-rays they found that many of the molds could no longer grow on minimal medium (Fig.11.10).

If amino acids were added to the medium, so as to make it complete some of these organisms were able to survive. By adding amino acids, one at a time, to the culture of the irradiated mold, they were able to separate out groups of organisms that needed one particular amino acid. The inability of the mold to produce a particular amino acid means that the mold has lost the ability to synthesize that enzyme needed to make the amino acid. This meant, in turn, that the organism had lost the gene that directed the synthesis of that enzyme. The X-rays had caused a mutation in the gene that normally causes the synthesis of the enzyme. From the result of these experiments, it was

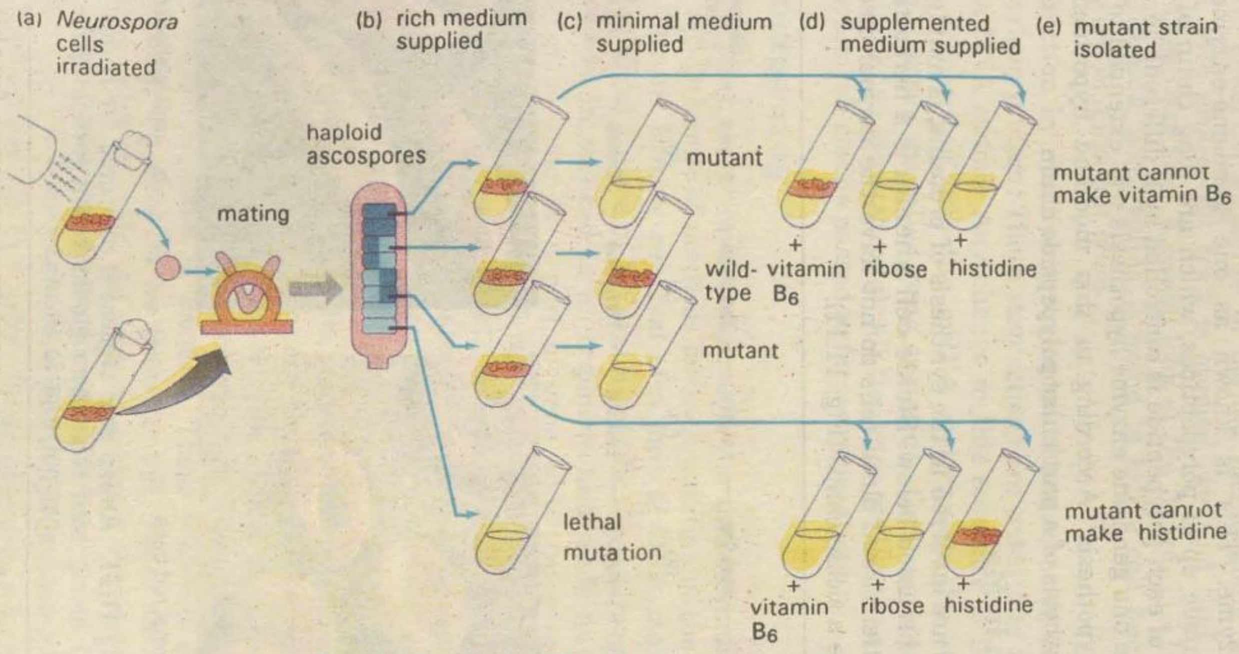
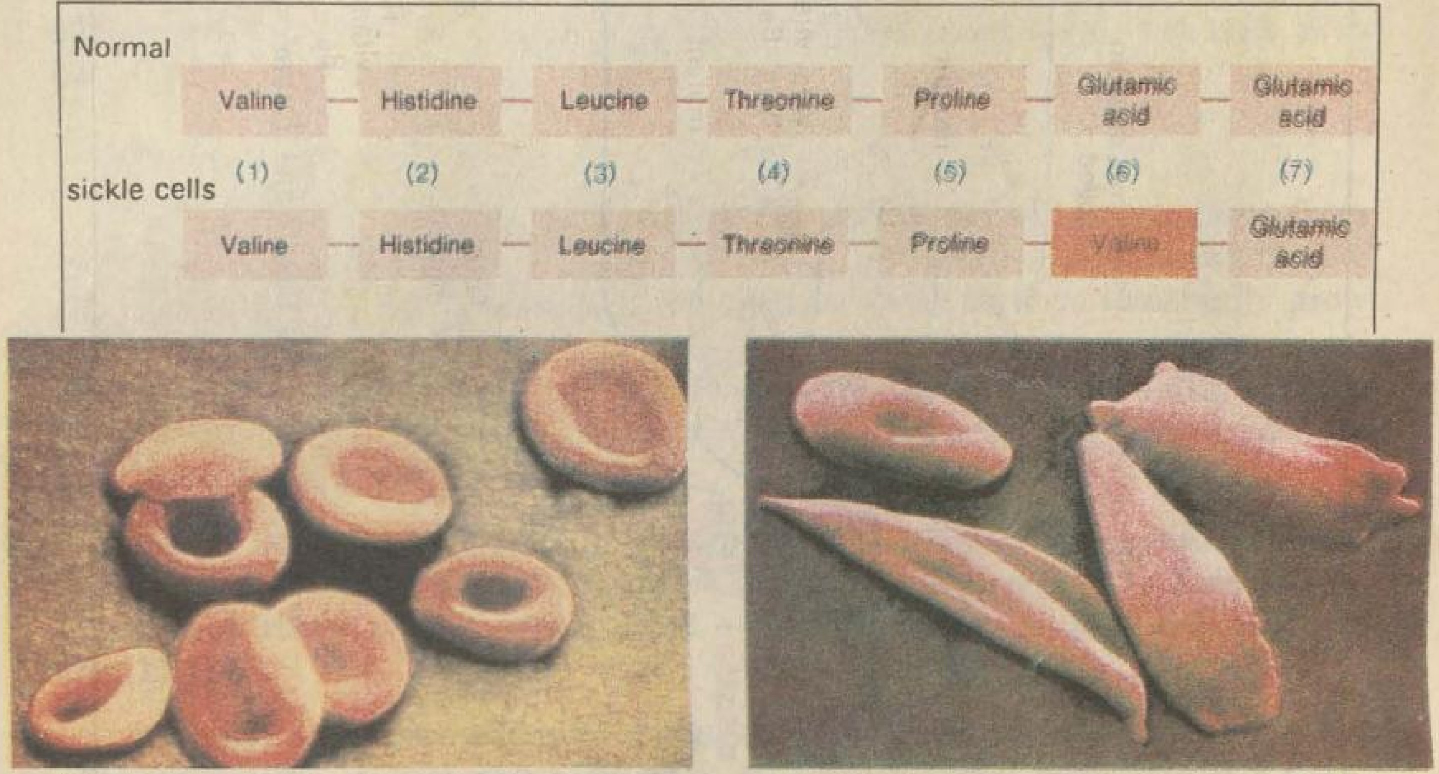

(a) Neurospora cells irradiated
(b) rich medium supplied
(c) minimal medium supplied
(d) supplemented medium supplied
(e) mutant strain isolated
haploid ascospores
mating
mutant
wild-type
mutant
lethal mutation
+ vitamin B6
+ ribose
+ histidine
mutant cannot make vitamin B6
+ vitamin B6
+ ribose
+ histidine
mutant cannot make histidine

Fig 11.10. Work of Beadle and Tatum on Neurospora.

concluded that each gene produces its effect by controlling the synthesis of a particular enzyme. This is known as one "gene-one-enzyme hypothesis." Proteins are made up of polypeptides, which are long chain of amino acids. The synthesis of each polypeptide is controlled by a different gene. Because of these facts, the one gene-one enzyme hypothesis was extended to one gene-one polypeptide hypothesis. According to this modified hypothesis each gene directs the synthesis of a particular polypeptide chain.

Gene Action in Man

The genes are involved in the synthesis of proteins, is amply explained by the example discussed below. **Sickle cell anemia** is a hereditary disease in which the patient's red blood cells do not have the normal disc shape. They instead assume a sickle shape (Fig. 11.11).


Normal
Valine — Histidine — Leucine — Threonine — Proline — Glutamic acid — Glutamic acid
(1) (2) (3) (4) (5) (6) (7)
sickle cells
Valine — Histidine — Leucine — Threonine — Proline — Valine — Glutamic acid

a. Normal red cells

b. sickle shaped red cells

Fig 11.11. Amino acid sequences compared for normal and sickel hemoglobin in the portion of the one polypeptide affected.

A person with the disease is homozygous recessive for this haemoglobin gene. The red blood cells in this case do not carry oxygen like the normal red blood cell.

When the chemical structure of normal haemoglobin and that of the haemoglobin with sickle cell trait is studied, we find that there is slight difference between the two. A casual look at the figure. 11.11 will show that in place of glutamic acid, valine is found in sickle cell haemoglobin. This happens because of a mutant gene.

Genes function by specifying the order of amino acids in a polypeptide chain for a certain protein. These instructions are coded into the sequence of bases along a DNA strand. Any change in this sequence is likely to change the message transcribed into the mRNA and change the structure of the protein. Such changes are called **gene mutation.** Once a mutation occurs in a DNA molecule, it is copied through all the later replications of the DNA. A mutation in a sex cell can be passed to future generations.

Genetic Engineering

One of the most remarkable outcome of the understanding of the gene has been the development of methods for manipulation of the DNA of a cell. These manipulations involve removal of a part of DNA molecule from the genome or addition of a piece of DNA at a specific site in the genome. A gene of a choice may be introduced in an organism and made to express specific product. A defective gene or a part of gene which may be the source of physiological disorder can be cut and removed out of cell. One of the goals of genetic engineering is to correct genetic defects by transferring normal genes to cells that lack them. Hereditary disease could possibly be treated in this way. Another goal is to give desired properties to plants and animals that are raised for food or other purposes.

For introduction of genes into cells, some carrier molecules also known as **vectors** are used. The genes of choice are placed on these vectors which are then introduced into other organisms or cells. Different types of vectors are being used these days but the most common are **plasmids** which are small circular DNA molecules found in bacteria. These plasmids are placed in a solution containing the gene to be transplanted. These foreign genes are usually obtained from animals. An enzyme called a **restriction enzyme** is then used to break open the plasmid ring. The free genes in the solution attach themselves to the open ends of the plasmid thus closing the ring again. The plasmid now include the new gene. These plasmids which have another gene incorporated in them are known as recombinant **DNA** and hence this technique is also called as **Recombinant DNA technology** (Fig. 11.12)

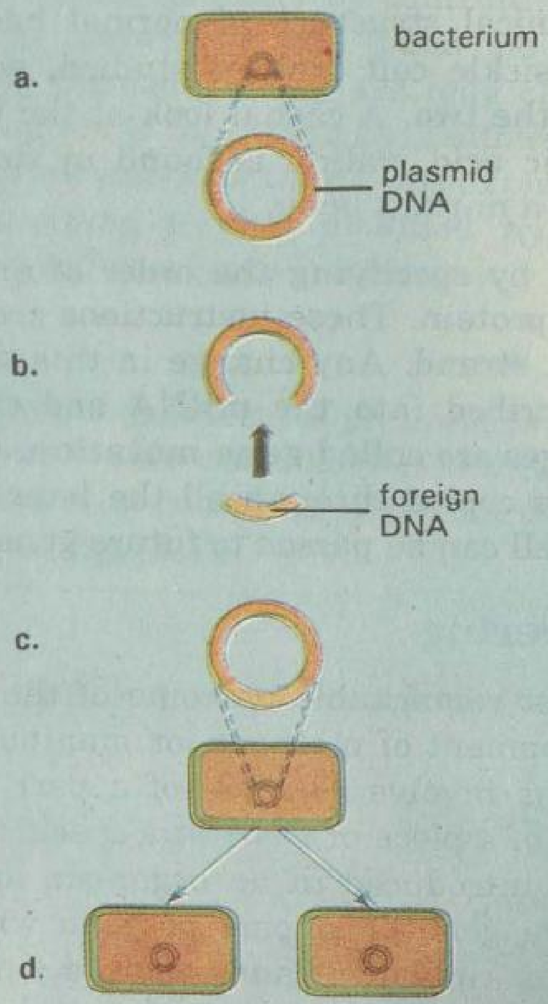


Fig 11.12. Gene cloning procedure plasmid DNA is removed (a) from *E. coli* (b) foreign DNA is incorporated or *spliced* into the plasmid, which is then (c) reintroduced into the bacterium. Here it (d) directs protein synthesis and replicates normally.

Bacteria are then exposed to the altered plasmids and many of the bacteria will take them in. Once inside the bacterial cells, the transplanted genes begin to be expressed. The bacteria produce the protein specified by the gene. This protein may be one of a number of desirable products that are difficult or expensive to obtain by other means. Among the proteins that are currently the objects of research efforts are insulin, human growth hormone and human interferon. Several companies have found in recent years to develop recombinant DNA technology on a commercial scale. Some of the new forms of bacteria produced by this research have even been patented.

QUESTIONS

1. Define the following terms:
    - Codon
    - Anticodon
    - Purines
    - Pyrimidines
    - Genetic Engineering
    - Nucleotide
    - Plasmid
    - Transcription
2. Describe Watson and Crick's model of DNA.
3. How did Hershey and Chase demonstrate that DNA carries hereditary information?
4. Describe how a DNA molecule replicates?
5. Compare the chemical composition and structure of DNA with RNA.
6. What hypothesis did the experiments of Beadle and Tatum suggest?
7. Give an account of the process of protein synthesis.
8. What is genetic engineering? How do genetic engineers use plasmids?
9. The sequence of bases of one strand of a DNA molecule is GAC GTAC. What is the sequence of bases of the other strand?
10. Compare replication with transcription.
11. Suppose that you knew which gene or genes control the production of growth hormone. Suggest a way that you might produce the hormone in large quantities.

EVOLUTION

12

In the previous chapters, we have studied that a great variety of organisms inhabit every part of land and sea. They differ greatly from one another in their shape, size and structure. It is interesting to note that their fossil remains show structural resemblances with the organisms present today.

The study of fossils reveals that the organisms that inhabited the earth in the past, show some structural resemblances with the ones living today. Does it mean that the organisms living today are related to those that lived in the past? Further more, does it also mean that the organisms living today have changed from the ones that lived in the past? If so, it would imply that the living things can change. This concept is called **Organic Evolution**. This organic evolution is defined as **"Descent with modification through times"**.

The evolutionary concept is, no doubt, based not only upon the comparison of the structures of living and fossil forms but is strengthened by the appearance and extinction of different species in the past, upon the existence of physiological and biochemical similarities and differences between various species, by the analysis of genetic constitution of the plants and animals living today, alongwith other aspects. Why, for example, ATP is associated with the energy reactions in all the cells of the organisms and DNA carries the hereditary instructions? These fundamental similarities cannot be regarded as mere coincidence and can only be accounted if we assumed that the living things have a common pattern and are interrelated through evolutionary descent.

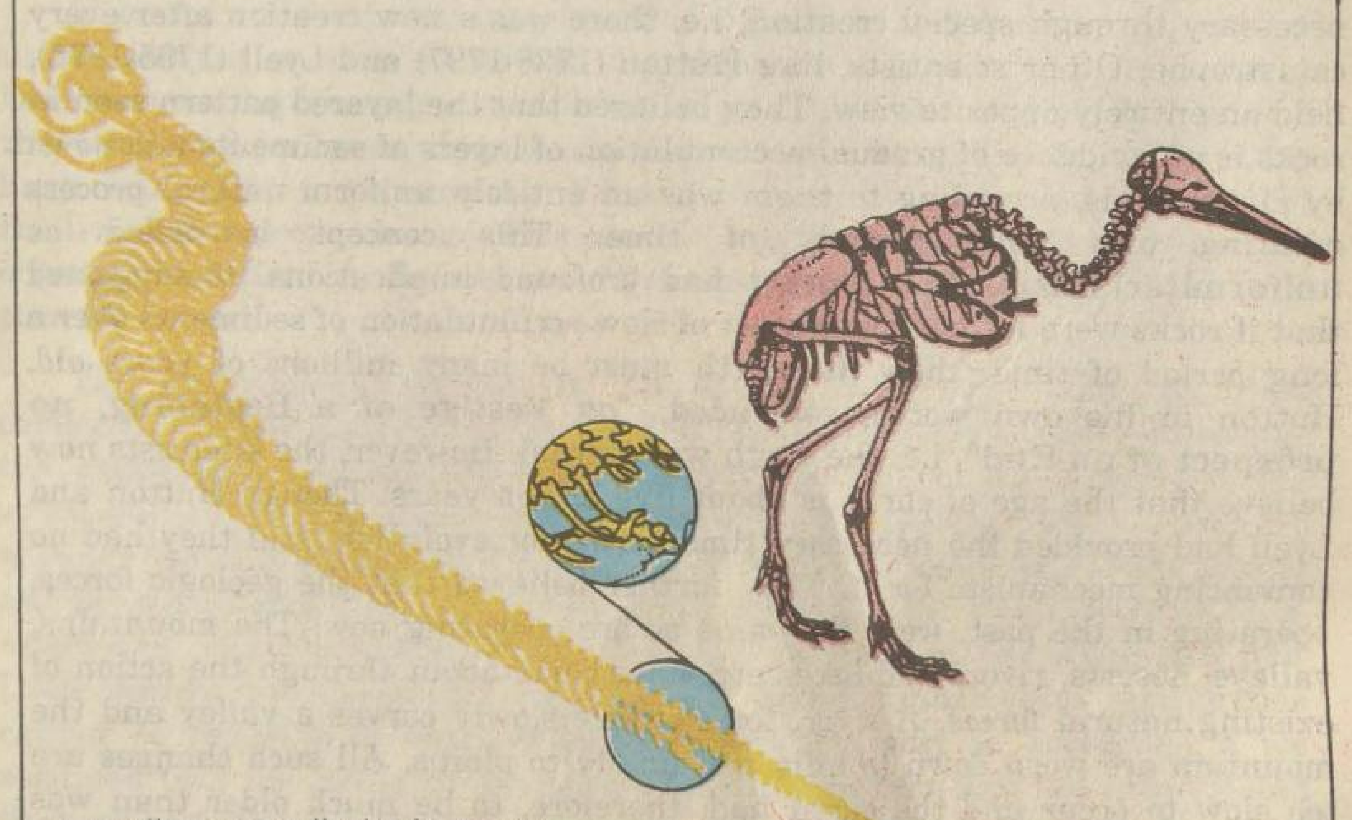
The idea that the organisms living today evolved from the simpler ones that lived in the past, is quite old.Early Greek philosophers have mentioned it in their writings. However, the idea presented was quite vague as they had little knowledge of Biology. Aristotle (384-322 B.C), however, worked out an elaborate theory of evolution. He believed that living organisms, gradually evolved into new organisms as nature tended to change from simple, imperfect form to complex and perfect form. However, more and more people started taking interest in the concept of organic evolution from the nineteenth century onwards.

Various fossils, representing pieces of bones, teeth or shells of animals had been found from the rocks by the early workers. Some of them resembled the living animals, but others did not. It was Leonardo da Vinci who correctly identified them to be the remains of the animals that lived in the past and no longer occured now. This evidence of life in the past led to the formulation of theory called theory of **catastrophism** (Georges Covier 1769-1832). According to the theory fires, flood and other havocs destroyed the living things periodically in the past. A repopulation of the world therefore, became necessary through special creation, i.e. there was a new creation after every catastrophe. Other scientists, like Hutton (1726-1797) and Lyell (1795-1875), held an entirely opposite view. They believed that the layered pattern seen in rocks is an evidence of gradual accumulation of layers of sediments laid down by rivers. This, according to them was an entirely uniform natural process occuring over long periods of time. This concept is called as **uniformitarianism.** This concept had profound implications. It suggested that if rocks were formed as a result of slow accumulation of sediments over a long period of time, then the earth must be many millions of years old. Hutton in his own words, concluded, "*no* **Vestige of a Beginning, no prospect of an End"**, i.e, the earth was eternal. However, the scientists now believe that the age of earth is about five billion years. Though Hutton and Lyell had provided the necessary time period for evolution, still they had no convincing mechanism for it. They further believed that the geologic forces, operating in the past, were the same as are operating now. The mountains, valleys, deserts, rivers and lakes etc. have come about through the action of existing natural forces. A river, for example slowly carves a valley and the mountain are worn down to hills and finally to plains. All such changes are too slow to occur and the earth had, therefore, to be much older than was generally believed at that time.

This belief triggered Darwin's imagination which finally paved the way for making possible the formulation of ideas regarding the theory of organic evolution which he presented in his book *"The Origin of Species by means of Natural Selection" in 1859*

Theories of Organic Evolution

Darwin was not the first to present the theory of organic evolution. Many workers in 19th century presented their hypotheses about how the organic evolution could occur. One of the first to present a mechanism for evolution was Lamarck (1744-1829). The theory put forth by him stated that traits acquired by the parents during their life time could pass on to their offspring. The theory known as **Lamarckism** was actually an attempt to explain many striking adaptations of plants and animals to their environment. Lamarck was also impressed by the occurence of changes in the fossils. He observed that the older fossils tended to be simpler, while younger fossils were not only more complex but also more like the existing organisms. Thus in 1802 he hypothesized that the organisms evolved through the inheritance of **acquired characters. Living organism could modify their bodies through use and disuse of parts. The organs put to more use, get developed, whereas those that are put to lesser use or are not used tend to become lesser developed. Thus**


a) Rudimentary limbs in snake

b) Rudimentary wings in kiwi.

Fig 12.1. Reduction of organs through disuse

such organs become modified during the life time of the individual. Lamarck believed that these modifications could be transmitted to their offspring. He believed that all the organisms possess an innate drive or an urge to achieve perfection or in his own words an urge to climb the **"ladder of the nature".** His most famous illustration was that of the giraffe, wherein he showed that use and disuse of certain organs, i.e. elongation of forelimbs and neck combined with the mechanism of innate drive for perfection had produced radical changes in the forms of organs i.e. evolution of new species. These changes according ,to Lamarck resulted in the evolution of new species.

Many examples were cited in support of Lamarckism, e.g. complete loss of limbs by snakes which come from lizard like ancestors, loss of wings by the running birds, such as Kiwi and Ostrich (Fig.12.1). Lamarckian theory of the inheritance of acquired characters, was quite attractive and could reasonably explain the adaptation of many organism. However, it left many things unexplained and hence was unacceptable. For instance it is well known that alterations in the soma can be brought about without influencing in any way, the hereditary informations in the gametes. Therefore, the hypothesis of inheritance of acquired characters had to be rejected.

Hence the other theory which explains more successfully the evolutionary phenomena, and has been revised in the light of modern knowledge, is the theory **of natural selection.** It was first proposed by Charles Darwin and Alfred Wallace independently in 1858.

Darwin's Theory of Natural Selection

Darwin was interested in the study of nature. He accompanied as Naturalist on ship, H.M.S. Beagle, which was to take a five years (1831-1836) cruise around the world. During this voyage Darwin had an opportunity to study animals and plants and the geologic formations of east and west coast of South America. The ship, as the map shows, then visited the Galapagos island west of Ecuador (Fig 12.2). Here, Darwin was fascinated to see the diversity of giant tortoises and the finches that inhabited these islands. Darwin was much impressed by these observation. He rejected the idea of special creation and thought about an alternative explanation for his observations. After his return to England, he spent another twenty years or so accumulating more facts that eventually led to the writing of his famous book"The Origin of Species".

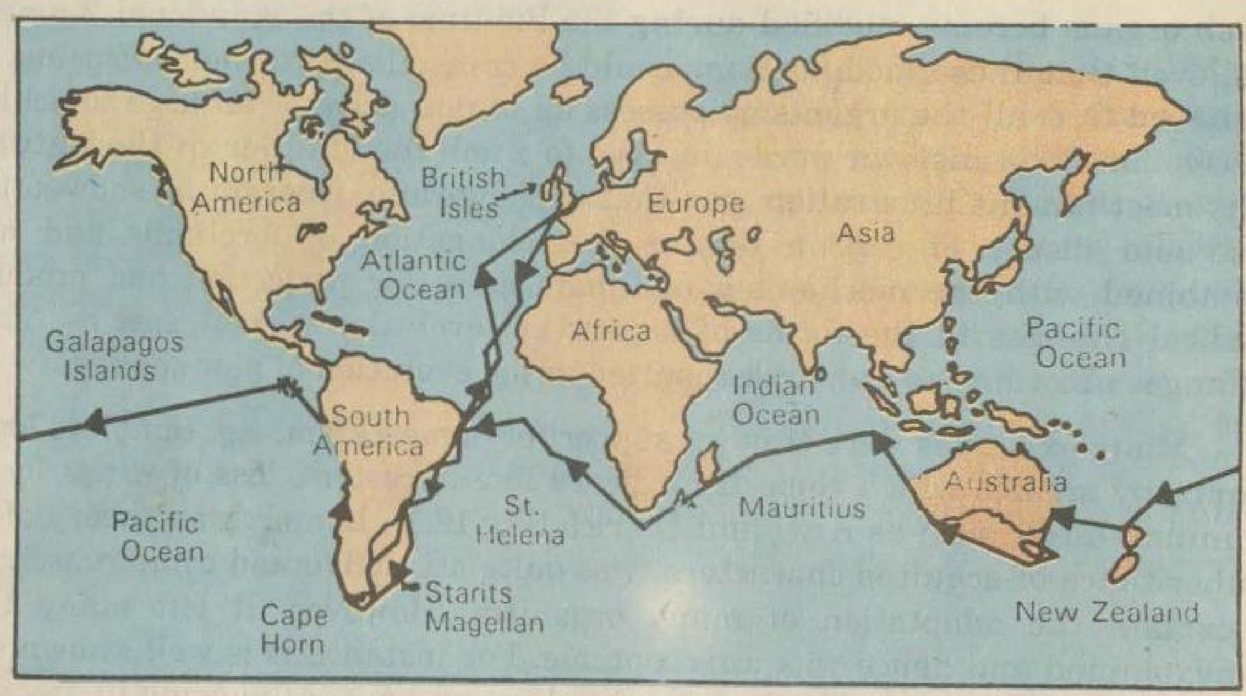

North America
British Isles
Europe
Asia
Atlantic Ocean
Africa
Pacific Ocean
Galapagos Islands
South America
Indian Ocean
Australia
St. Helena
Mauritius
Pacific Ocean
Starits Magellan
Cape Horn
New Zealand

Fig 12.2. Map showing the Voyage of Darwin on H.M.S Beagle

Wallace was a contemporary of Darwin. Although the social and educational backgrounds of the two was different, yet in some ways they

Fig 12.3. Charles Darwin (1809 - 1882)

became very similar. Both had travelled extensively in the tropic and had studied a large variety of plants and animals. Both had observed that many species showed considerable variability among individuals and at the same time the characteristics of different species were sometimes remarkably similar. Both were impressed by an article "*An Essay on Principle of Population*" by Malthus.

In 1858, however, two remarkably similar papers from Darwin and Wallace were presented to the Linnean Society, London. Next year (1859), Darwin published his monumental book *"On The Origin Of Species By Means Of Natural Selection"*.

Essential Features of the Theory

The salient features of Darwin-Wallace theory are summarized as follows:

1. The individuals comprising a population vary in their ability to exploit the available resources in nature. It is also a matter of common observation that no two individuals of a population are exactly alike. Actually variation is the characteristic of every population, whether of animals or plants. Darwin and Wallace believed that apparent variability was one of the innate properties of all living things. It is now known that **variations** are of two kinds i.e. **heritable** and **non-heritable.** Only the heritable variations, produced by mutation, provide the raw material for evolution.

2. The population of all the organisms tend to increase rapidly i.e., they have a tendency of **over production.** If unchecked, organism can produce far more offspring than can possible survive because of limitations of space, food and shelter etc. The number of members of each species remains fairly constant under natural conditions. Therefore, it can be assumed that most of the offspring in each generation die. If all the members of a species in a generation survive and reproduce, they would soon cover the earth. *Paramecium,* for example, divides three times a day. If all the descendants of single *paramecium* survive and continue to divide at this rate, then the total mass of protoplasm produced by the descendants in a period of five years would be not less than ten thousand times the mass of the earth. Similarly, a cod fish lays millions of eggs during one breeding season. If all the eggs laid by the fish develop into fishes, then whole of the sea would get filled up with them. Elephant, considered to be one of the slowest breeders among vertebrates, begins to breed at the age of thirty and continues to do so till the age of ninety

During this period a female elephant produces about six young ones. Darwin calculated that one pair of elephants would produce about nineteen million descendants in a period of seven hundred and fifty years. These examples illustrate the tendency of every organism to produce much more offspring than can possibly survive.

3. Since large number of offspring are produced than can possibly survive, there is always a struggle for survival i.e. a competition for food, light, water, space and a mate etc. Such a competition may be an active one. i.e. kill or be-killed, or it may be less apparent immediately but none-the less real, such as struggle of the plants to survive cold, draught, or other unfavourable environment conditions.
4. Which organisms survive and reproduce, will depend on their relative ability to exploit the resources needed for their survival. Organisms with variations that better equip them to survive in a given environment, will be favoured over the others that are less well adapted. In other words, the organisms which are fully adapted to their environment have higher survival chances, and nature will select such organisms for future propagation and continuity of their generation. These phenomenon were termed as the ***Survival of the Fittest or the Natural Selection,*** and this is the core of Darwin-Wallace theory of organic evolution.
5. As some of the variations among individuals are due to genetic differences, therefore they are heritable. The surviving individuals over the course of many generations will give rise to individuals that show changes in their genetic make up from the ancestral population. This is **evolution.**

The Mendelian laws of genetics had not been discovered at the time Darwin wrote his book. Darwin's assertion therefore, that variations among the individuals of a species population exist, was an untested assumption. Although Darwin could not explain the operation of inheritance, yet his theory made two important predictions which are correct. These are (i) the inheritable variation do not disappear from the population (ii) the variations that appear in a natural population arise purely by chance. It is known that mutations are source of variations. They indeed arise by chance and only a few turn out to be favourable.

Darwin's theory of natural selection was apparently so reasonable and well supported by arguments that it was soon accepted by many biologists. Some however, objected that the theory could not explain the presence of many apparently useless structures in the body of an organism. Such structures may not be important for survival and may simply be incidental effects of genes. In short, the concept of struggle for existence and survival of the fittest were the key points in Darwin-Wallace theory of natural selection.

Evidences in Favour of Organic Evolution

Darwin, in his book, "The Origin of Species", said that all the living things on earth were here as a result of descent with modification from a common ancestor. In this book, he presented a large number of facts which could best be explained only by Theory of organic evolution. A brief overview of the evidences in favour of organic evolution is given below:

1. Evidence from Classification

The principles of classification have been discussed in the previous chapters. The theme of classification is based upon the resemblance which various organisms show among themselves. It is known, for example, that all the members of the phylum Chordata have, at some stage in their life, a notochord, pharyngeal gill slits and a dorsal hollow central nerve tube. These remarkable resemblances can only be interpreted by assuming that all the Chordates had a common ancestor. The resemblance of all the orders of a class will be close and the various species placed in the same genus will be so close to one another that only a specialist may be able to tell them apart. The mere placement of different organisms in groups and sub groups on the basis of their resemblance to one another suggests that they may have evolved from some common ancestor.

2. Evidence from Homology

In the previous chapters it has been seen that various systems in different species have a close resemblance not only in their general plan, but also in their other structural details. In the skeletal system, for example, bone for bone correspondence can be seen in diverse vertebrates. Despite their diversity of functions the internal anatomy of the fore limbs of a bird, dog, whale, bat and human is remarkably similar (Fig. 12.4). Similarly in other systems though some differences can be see, yet the resemblances are more conspicuous. Such basically similar structures are termed as **homologous structures**. These can only be explained if we assume that all the animals have evolved from a common ancestor.

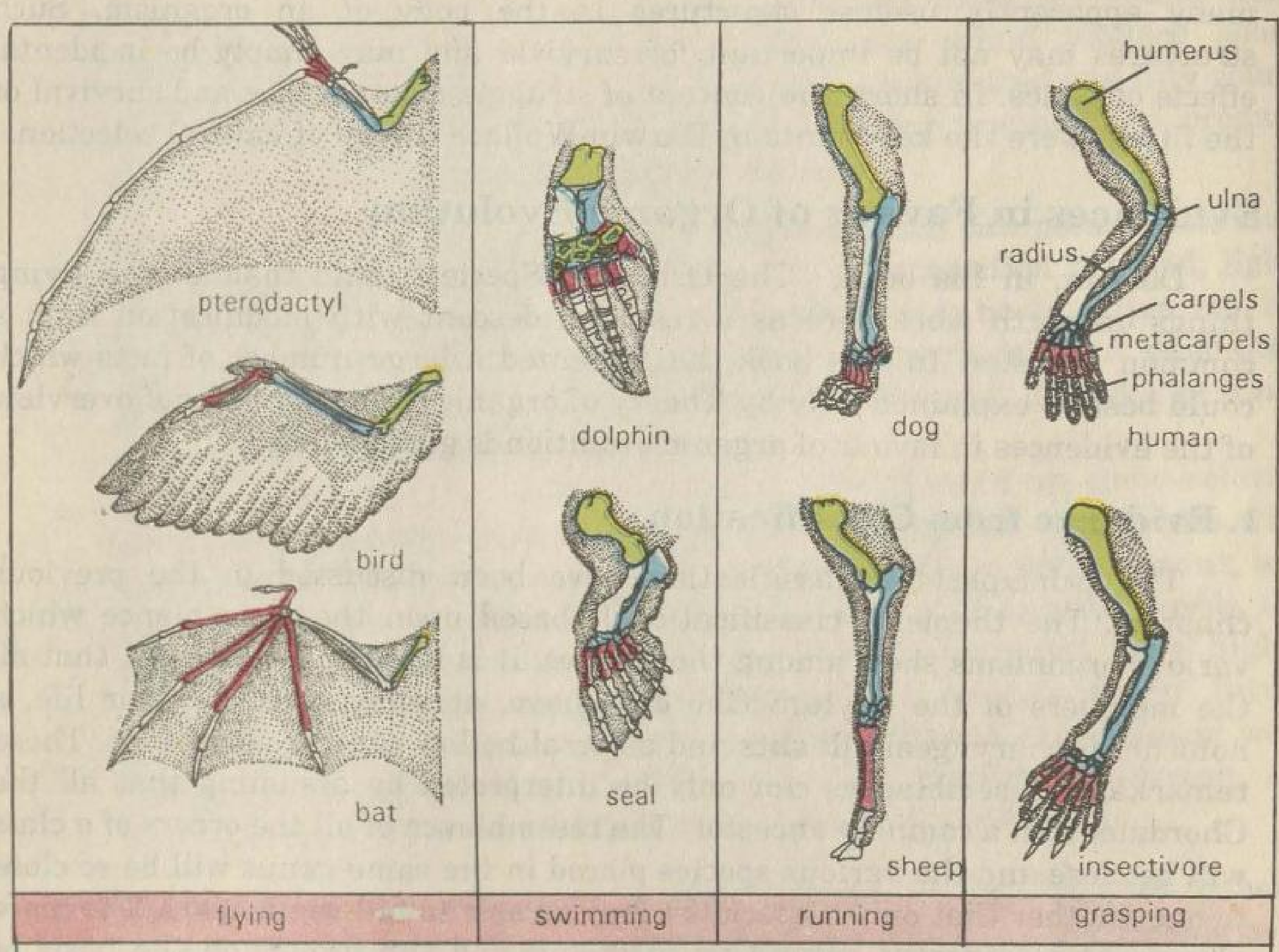

pterodactyl
bird
bat
dolphin
seal
dog
sheep
humerus
ulna
radius
carpels
metacarpels
phalanges
human
insectivore
flying
swimming
running
grasping

Fig 12.4. The bones of forelimbs of various animals showing similarity in structure despite wide differences in functions.

3. Evidence from Vestigial Organs

In almost all the plants and animals some organs that serve no apparent purpose are found. Such organs are called the **vestigial organs.** For example, the pelvic bones in whales and certain snakes occur as embedded inside the muscles and thus do not seem to perform useful function as these animals do not possess hind limbs. They either swim in water or crawl on land. These vestigial structures are homologous to important structure found in other vertebrates where they are well developed and serve useful function. The wings of flightless birds such as kiwi and ostrich are also examples of vestigial organs serving no useful function, but had neither been lost completely nor modified into different structures.

The human body is not without its quota of vestigial organs. The appendix, coccyx, nictitating membrane and ear muscles are some of the examples. The appendix, a small finger like process, that leads off from the large intestine, has unknown function. However, in other animals, such as rabbits, it is well developed and serves a useful function in digestion. The coccyx is the tail bone which is well developed in most of the vertebrates, but is of no use in human. The nictitating membrane is well developed in birds, serving the function of cleansing the eye ball. But in human it is highly reduced and serves no function. Similarly, the muscles of the ear are of little use to the human, whereas in other mammals as dogs and horses, they move the pinna of the ear to collect the sound waves from various directions (Fig. 12.5).

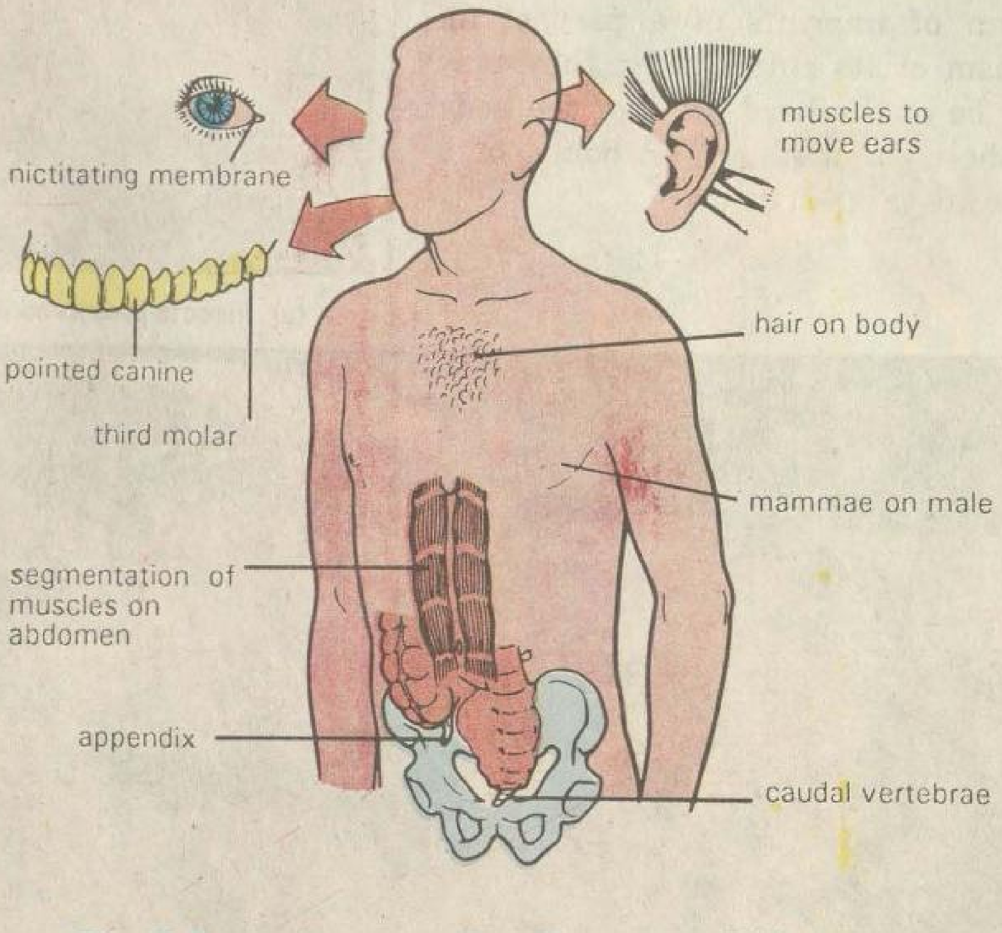

nictitating membrane
muscles to move ears
pointed canine
third molar
hair on body
mammae on male
segmentation of muscles on abdomen
appendix
caudal vertebrae

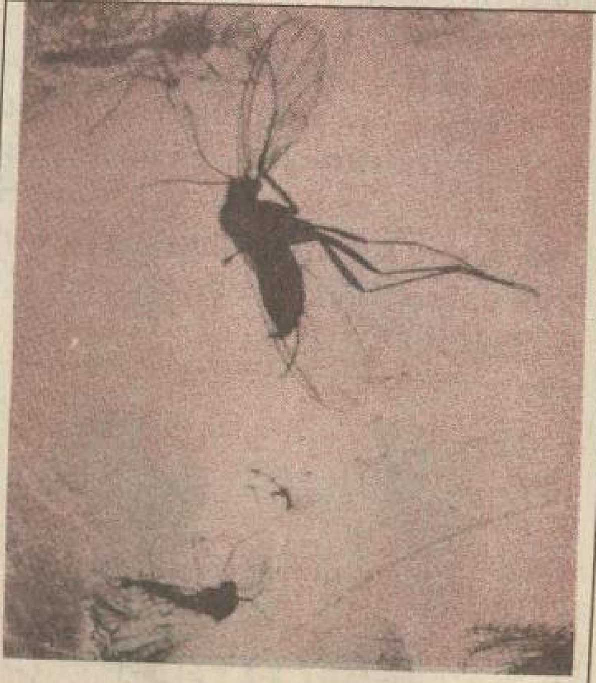
Fig 12.5. Various examples of human vestigial organs

4. Evidence from Comparative Biochemistry

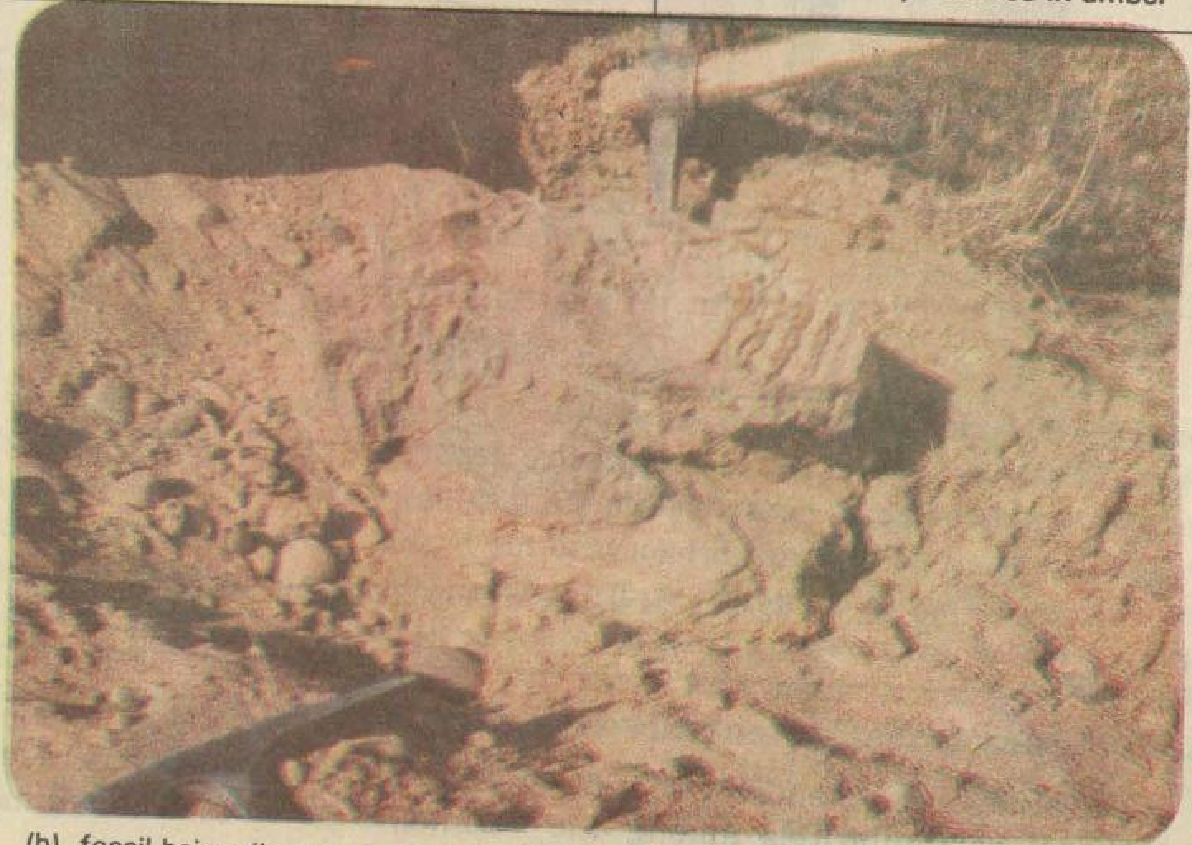
The study of biochemistry in different animals and plants has revealed a great deal of similarities among the various organisms. The amino acid sequences in proteins and the similarities in the composition of DNA and RNA have confirmed that all living organisms are related to each other. Similarly, most vertebrates share the same or similar hormones. These similarities suggest relationship among animals and plants.

5. Evidence from Palaeontology

Fossils are different sorts of remains of organisms that lived in the past geologic ages. An important evidence in favour of evolution is provided by them. Different type of fossils have been found over most part of the earth. The fossils may either be in form of imprints of a part of an organism or its entire body: they may either be of the hard parts of the body like shells of molluscs or bones of a vertebrate (Fig 12. 6a, b).



(a) Insects preserved in amber



(b) fossil being dig out

Fig 12.6. Various fossilized animals

Over the years, some fossils have been found which present intermediate stages leading from an ancient form to the modern form. Such graded series are known as **connecting links.** Fossil horse is one of such series of fossils (Fig. 12.7).

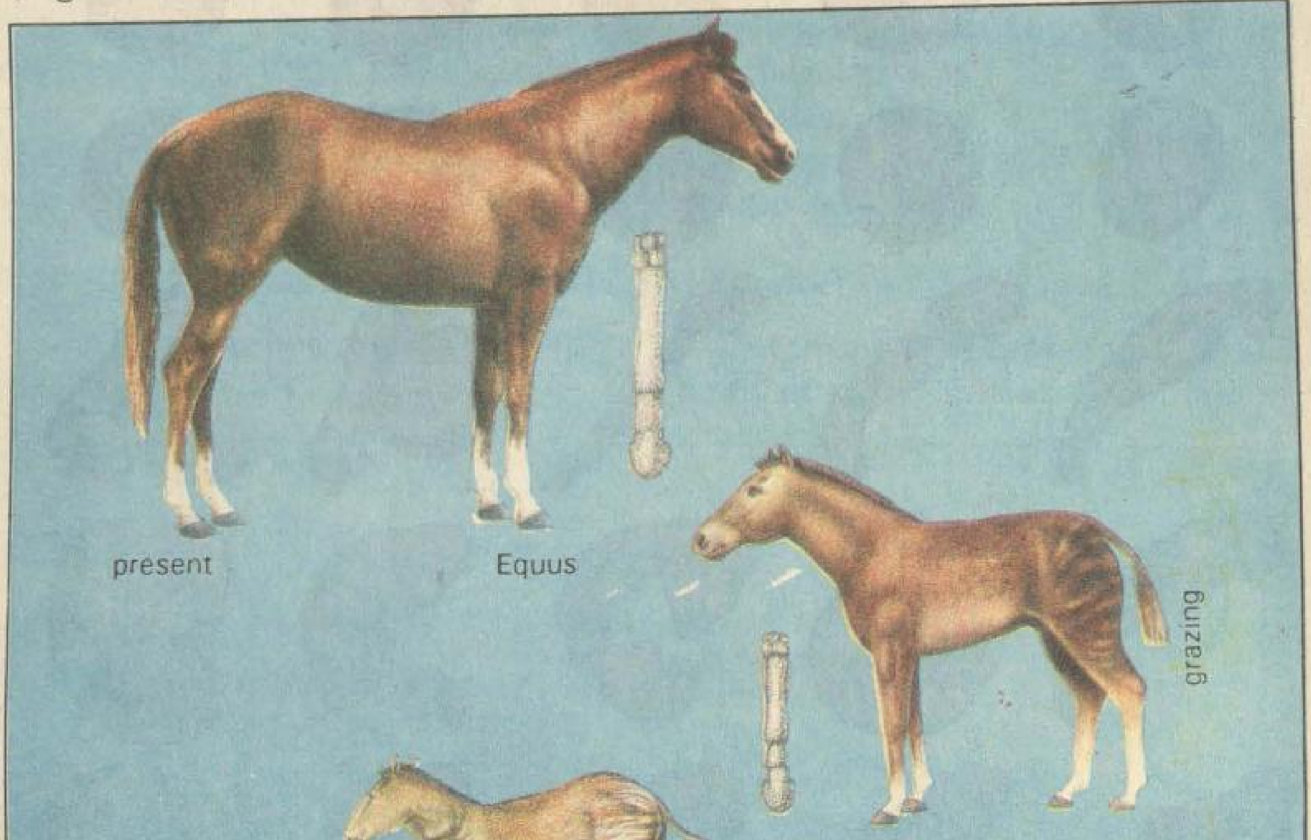
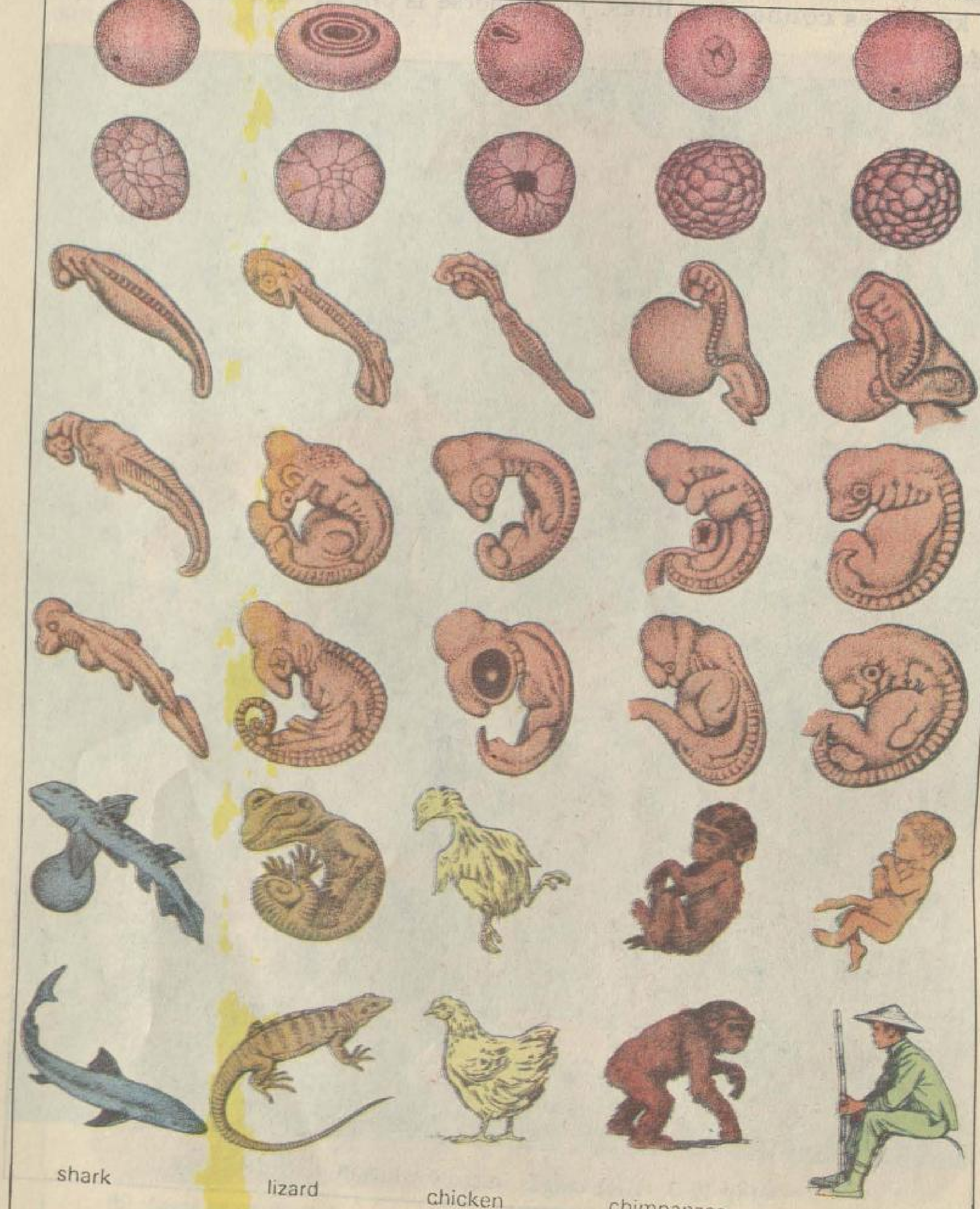

present
Equus
grazing
Pliohippus
25 million years ago
Merychippus
browsing
Mesohippus
50 million years ago
Hvracotherium
Eohippus

Fig 12.7. Five stages in the evolution of Horses

6. Evidence from Embryology

The embryological development in all the vertebrates show striking



shark
lizard
chicken
chimpanzee
human

Fig 12.8. Camparison of vertebrate embryos

similarities particularly during the early stages of their development. They evidently are indicative of close relationship between these animals. All these animals pass through a stage during their development when their embryos possess gill arches. Only fishes go on to develop the gills, whereas in others they disappear (Fig 12.8). It appears, as if, vertebrates other than fishes are just repeating their history during their development. The idea that embryological development repeats the evolutionary history of the species, is called the theory of **recapitulation.** The theory is not restricted to the vertebrates only, but is valid to the other organisms as well.

7. Evidence from Geographical Distribution

P. L. Sclater had proposed in 1858 that the continental areas of the world can be divided into six regions on the basis of their animal distribution

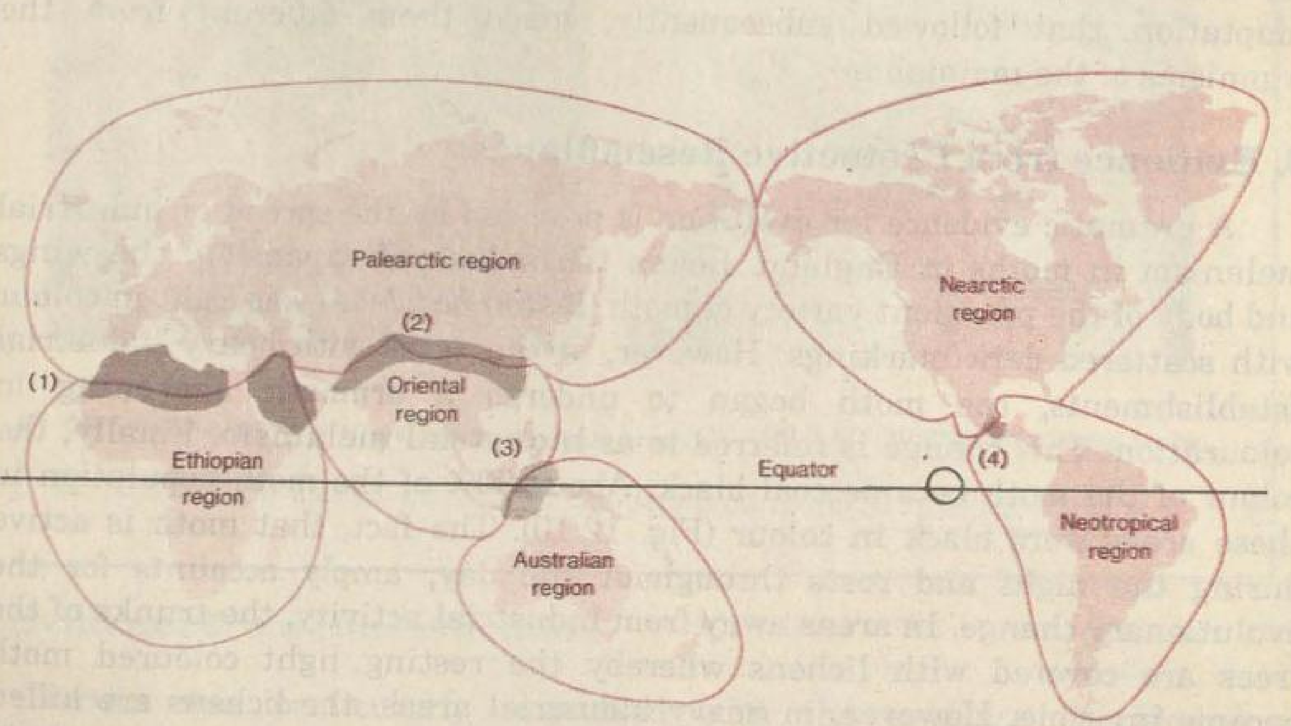


Fig 12.9. Wallace's faunal regions. The circle on the equator shows the location of the Galapagos Islands.

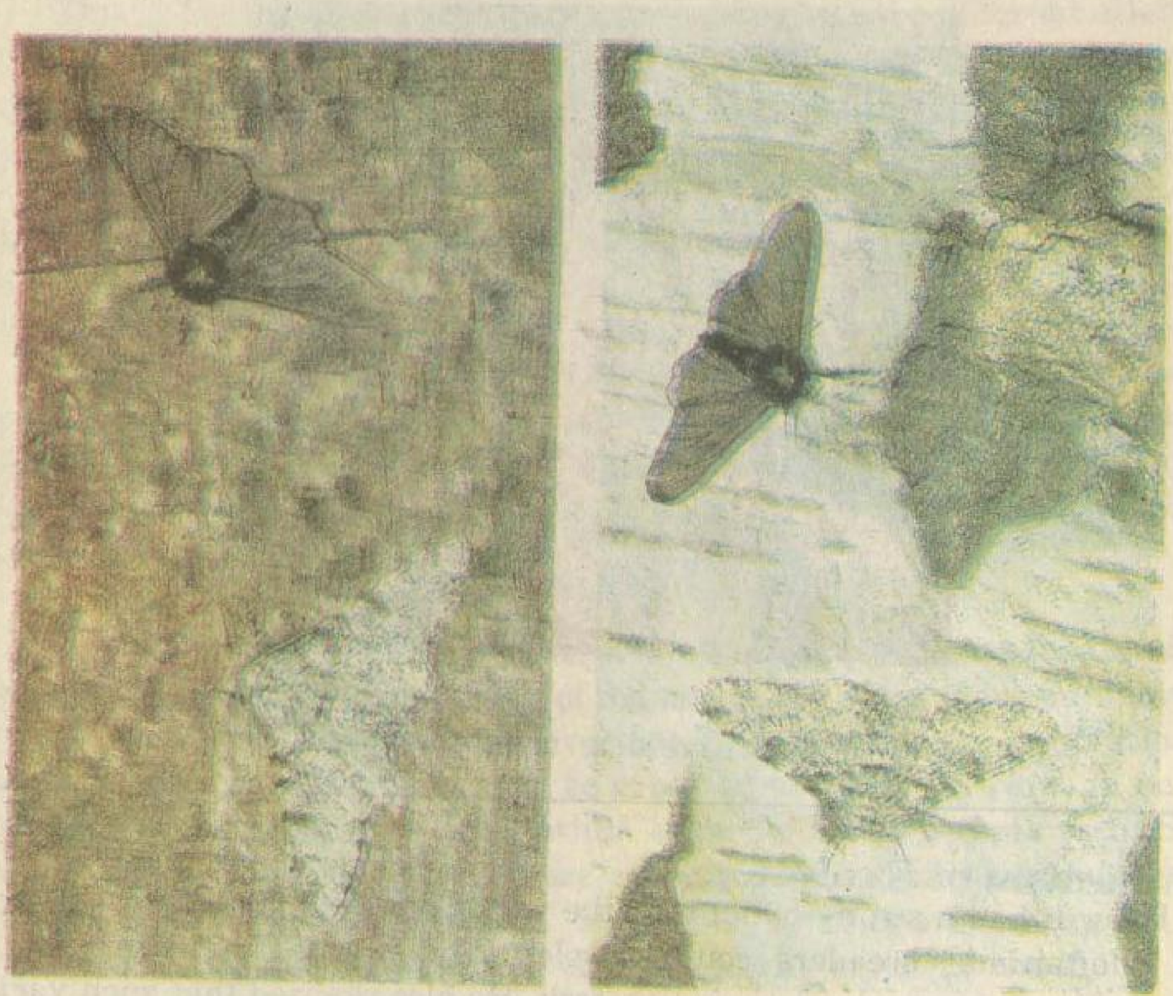
(Fig.12.9). These regions were accepted by A. R Wallace and others. Of these, the two tropical areas, Ethoipian and Oriental,possess the greatest diversity of the living things. In the Palearctic and Nearctic regions the spread of fauna and flora has often been greatly limited by the harshness of the climate. The

remaining two regions, Neotropical and Australian, have been intermittently isolated from the mainland and thus show an unusual fauna and flora.

The distribution of plants and animals in the oceanic islands provides particularly strong support for the evolution theory. These are the ones which have never been connected with the mainland mentioned above. Darwin, during his voyage on the ship. M.S BEAGLE visited Cape Verde islands near the equator, off the coast of Africa. Several years later, he visited the Galapagos islands near South America and was surprised to witness the similarity in the climate of the two places. However, he was astonished to find totally different fauna and flora of the two places. He found that animal and plant life present in Galapagos island though differed from that of the mainland, yet presented a basic similarity. It made Darwin to think that each of those organisms occuring there, were the result of descent, with some modifications (evolution) from common ancestor, which accidentally reached the island from their original home in South America. The isolation and adaptation that followed subsequently, made them different from the organisms of the mainland.

8. Evidence from Protective Resemblance

A dramatic evidence for evolution is provided by the spread of industrial melanism in moths in England. Before the industrial expansion, the wings and body of the prevalent variety of moth (*Biston betularia*) was light in colour with scattered dark markings. However, in the areas with heavy industrial establishments, the moth began to undergo a dramatic darkening in colouration. This change is referred to as **industrial melanism.** Finally, the colour of the moth became coal black. About 90% of the moth population in these areas were black in colour (Fig. 12.10). The fact, that moth is active during the night and rests throughout the day, amply accounts for the evolutionary change. In areas away from industrial activity, the trunks of the trees are covered with lichens whereby the resting light coloured moth become invisible. However, in heavy industrial areas, the lichens are killed by the toxic gases etc., thus making the branches and trunks of the trees dark in colour. Against such a background, the light coloured moth becomes easily visible and thus can easily be preyed upon by the predators. In such polluted areas the darker variety would have a much better chance of survival from its predators.



a) on a blackened tree trunk near industrial areas. b) on a lichen-encrusted tree trunk.

Fig. 12.10.The light and dark forms of the peppered moth, Biston betularia at rest on trunks.

9. Evidence from Domestication

Darwin was particularly impressed with the evidence provided by **artificial selection,** i.e., deliberate cultivation of plants and animals to achieve the desired results. Perhaps the most striking example of artificial selection among the animals is the extra-ordinary diversity seen in the domestic dog and varieties of pigeons. It provides ample evidence of human ability to alter a species by selective breeding procedure over a short period of time. Similarly lot of changes have been witnessed in the crops of maize, wheat and tomato etc (Fig.12.11).

Fig. 12.11. Selective breeding in the development of wheat.

Mechanism of Evolution

Darwin had a strong belief that the variations occur in nature. He found that the animal breeders could develop new breeds from variants that appeared spontaneously in their livestock. He also realized that such variants could not arise as a result of simple exposure to some new environment. In other words, only inherited variations and not those acquired during the life time of the organism, could serve the purpose.

Another important point in the formation of new variants is the selective breeding. Once the individuals with desirable characters were identified, they were mated together to yield results such as:

i) **a higher proportion of offspring with desired characters, and**

(ii) **An intensified expression of the trait by repeating the process of selective breeding. It was thus possible eventually to develop pure line of individuals always displaying the selected traits.**

If similar things happened in nature, then one could believe that evolutionary changes do take place. It appears that such things do operate in nature, as well.

To understand the process, let us imagine a field of pea plants, with flowers of red or white colour in which some plants have alleles for white flowers, while others for red flowers. Considering only the gene for flower colour, one may define a gene pool as comprising of all the different alleles of that particular gene found in that population. We can also determine the relative frequencies of the different alleles in the population by adding up the alleles that each plant possesses. Consider, for example, a population of 100 pea plants, which will have a total of 200 alleles for flowers colour, as each plant is diploid. Suppose that there is a total of 80 alleles for white colour; the alleles for red colour would naturally be 120. It means that the alleles frequency for white colour would be 80/200 x 100 = 40% or (0.4) and that of red 120/200 x 100 = 60% or (0.6). What would happen if this field were invaded by herbivores that ate up all the plants showing white coloured flowers before they had set seeds? As the red colour trait in pea plants is dominant over the white colour trait, therefore, the allele frequency for white colour will change in the population.

The red flowered plants that escape destruction will reproduce and the next generation will comprise again of red as well as white flowered plants. If this selective foraging continues over many generation, a population of homozygous red flowered plants can be expected to establish. Now, in such a population the allelic frequency of white colour will not become zero. Some alleles for white flowered condition are expected to exist in the population as concealed by the dominant allele. Thus due to selective eating by the herbivores, change in frequency of the genes will occur in the field. This simple example suggests three important points about evolution such as:

1. Selection does not bring about genetic changes in individuals but operates upon whatever variability the population possesses.
2. Evolution is a phenomenon that operates only at the population level in sexually reproducing organisms.
3. In reality evolution is a change in the allelic frequency of different alleles in the population produced as a result of differential reproduction or selection.

In short the word evolution, in its broader sense, really means *"a change in the allelic frequencies of a population"*

Before we study the forces that cause population to evolve, it will be helpful to consider the characteristics of a population that are apparently not changing i.e. the population is in equilibrium. Hardy and Weinberg (1908) working independently defined "populations in equilibrium" and also pointed out conditions which are responsible for keeping a population in equilibrium. According to Hardy-Weinberg Law *"under certain conditions of stability, both allelic frequencies and genotypic ratios remain constant from generation to generation in sexually reproducing populations".* Following are the assumptions that according to **Hardy-Weinberg Law**, must be met with for keeping the gene pool of a population in equilibrium.

a. There must be no mutation, as that would automatically change the allele frequency.

b. There must be no differential migration of genotypes into (immigration) or out of the population (emigration).

c. The population must be infinitely large.

d. The mating must be random, with no tendency for certain genotypes to mate with some other specific genotypes.

e. All the alleles must be equally adaptive, or adaptively neutral. This rules out natural selection.

Hardy and Wienberg observed that if all of these conditions are met with, the allelic frequency in the population will not change. However, even if one of the above cited assumptions is violated, the allelic frequency will change, i.e. evolution will be said to have taken place.

None of the natural population, however, are truly in equilibrium. One or more of the assumptions narrated above are often violated in natural population. We will now study the assumptions of the law one by one, not only to illustrate the inevitability of the process of evolution but also the mechanism by which it takes place.

Factors Bringing about Change in Gene Frequency

1. Mutations - Source of Raw Material for Evolution

Mutations are always occuring in populations though they vary tremendously in their impact. Some mutations may have no harmful effect at all, others may be lethal. There is no known way of stopping them. The rate of mutation of various alleles also vary. If one gene mutates once every hundred thousand gametes per generation, the other may mutate once every hundred million per generation. Moreover, as far as mutational equilibrium is concerned, very rarely the number of forward mutations per unit time is exactly the same as the number of back mutations. The result of this difference causes a **mutation pressure**, i.e. a slow shift in the allelic frequency of the genes in the population. The more stable alleles will tend to increase in frequency, whereas the more mutable will tend to decrease, unless some other factors offset the mutation pressure. Mutations are the source of new alleles on which other evolutionary processes can work. As such they are the foundation of the evolutionary changes.

Mutations do not arise as a result of environmental necessities. They simply appear spontaneously. The phenotypic traits that the mutations produce may be immediately helpful or harmful or may become helpful now and harmful later or vice versa. Thus the mutations provide a potential, and the natural selection acting upon the potential, produces major change in the gene pool.

2. Migrations

The word migration in its familiar biological context means the movement of organisms from one area to another. However, in the context of evolutionary biology, it simply refers to flow of genes between different populations. A gene pool in genetic equilibrium is one which neither accepts immigrants from other population, as these might introduce new alleles, nor it suffers loss of alleles by emigration. In natural population, however, both immigration and emigration are affected whereby the gene pool of the population changes. Among baboons for example, each social group (or troop) forms a relatively closed breeding unit. All the females mate with only a few dominant males. The juvenile males often leave the troop and may join another troop to become dominant males. Thus the offspring of one troop carry the genes to the other troops.

Migration, therefore, tends to change the gene pool of various populations. This factor enhances the spread of the advantageous alleles throughout the species. As a result the individuals possessing these alleles survive better and leave more offspring in troop after troop.

3. Population Size

A population has to be infinitely large to completely rule out the chance of changing the allelic frequencies. To see its significance, let us go back to the observation made by Darwin and Wallace, while formulating their theory of evolution. In nature all populations have a tendency and a tremendous potential for growth, but they remain limited to a relatively constant size due to limitation of resources. This means that majority of the organisms die before they reach the reproductive age. In other words only a small size of population actually serves as parents for the next generation. Which individuals would reproduce, depends entirely upon fitness and chance. Therefore, individuals better adapted to their environment are more likely to survive. However, chance is also of great significance. For example, a seed that happens to fall on a dry hillside, cannot grow to become a tree and produce seeds. Or even the most alert rabbit may be buried under piece of rock during an earthquake or a land slide. In reality, of course, no population is infinitely large in size, but many populations are large enough, so that chance alone is not likely to cause any significant change in allelic frequency of their gene pools.

Any breeding population with more than 10,000 members of breeding age is probably not significantly affected by random change. However, allelic frequency in small isolated population of say less than 100 individuals of breeding age, is highly susceptible to random fluctuations, which can easily lead to the loss of an allele from the gene pool, even if the allele is adaptively superior one. In small populations, there are relatively few alleles with intermediate frequency. Most of the alleles either tend to be lost or fixed. In other words, small populations tend to have a high degree of homozygosity. The large populations on the other hand tend to be more variable. This change in allelic frequency of small population, purely by chance, is called **genetic drift.**

4. Random Mating

Another condition for maintaining genetic equilibrium is that reproduction must be totally random. If certain phenotypes are choosy in selecting their mates, the gene frequency in population may become altered. However, organisms seldom mate strictly randomly, and there is abundant evidence that nonrandom mating occurs in natural population. The establishment of breeding territories, the use of courtship displays, and the existence of peck order, all lead to non-random mating. In each of such cases, a certain number of individuals fail to make their proportionate genetic contribution to next generation.

There are three common forms of non-random mating amongst animals:

1. In some species, as elephant seal, just a few males fertilize all the females. The few males that do succeed in mating, drive away the other

through physical combats, loud and threatening voices or threatening gestures.

2. Some animals tend to mate assortively, i.e. like mates with like, as is the case with human beings too.
3. In many animals, as birds, the selection of the mate is the prerogative of the female. The males display their qualities, as bright plumage (peacock), courtship dances (domestic fowls) or a rich territory as in many song birds. The female selects the mate by somehow evaluating the male. It is thought that many of the elaborate structural behaviours, found only in males, have evolved through the selective pressure of the female mate choice.

Darwin was much impressed with the structural changes that have occured due to mate selection. He actually used the term **sexual selection** to designate the process of evolution through the mate choice. Thus non-random reproduction in broader sense, or the sexual selection, is not fundamentally different from other forms of selection.

5. Equivalence of Genotypes

Last assumption of Hardy-Weinberg principle is that all the genotypes are equally adaptive. It means that none have any selective advantage over the others. Some of the alleles may be adaptively neutral, with the result that organisms possessing any of the many alleles of the same gene are all likely to survive equally and reproduce. But this is clearly not the case with majority of the genes. Natural selection would definitely favour such an allele which shows its advantage over its counter parts in the form of enhanced reproduction etc., in a changed environment. Although mutations provide the initial variability and the chance effects of genetic drift may cause some changes in gene frequency, it is the natural selection that finally molds the species to fit in its changed environment. Natural selection is then the guiding force for evolutionary change.

QUESTIONS

1. What are the believes which triggered Darwin's imaginations resulting in proposing the theory of natural selection? Explain it briefly.
2. How is the evolution of the long neck and forelimbs of Giraffe explained by Darwanism and Lamarckism? Which of the two explanations is more acceptable and why?

3. What are the evidences which can be put forth in favour of organic evolution? Explain three of these in detail?
4. Explain, how do protective resemblance and domestication provide an evidence in favour of organic evolution?
5. Discuss in detail the role of mutations which they play in providing a source of raw material for evolution.
6. How does random mating fail in nature to maintain a genetic equilibrium in the population?
7. Define Hardy-Weinberg principle. What is its significance in explaining the inevitability of organic evolution?

ECOSYSTEMS 13

Every organism lives under certain conditions known as its **environment.** Environment is a complex of many physical and biological factors, that not only provides food, water, oxygen and nutrients but also provides living organisms place to live and to reproduce. In general, organisms do not live singly but in the form of groups in their environment. A group of organisms, made up of individuals of the same species which occupy the same habitat and share the same resources is known as **population.** Populations of different species living together in the same area constitute a community.

Habitats:

A habitat is a specific place with a particular set of environmental conditions where organisms live. Habitats are named after some prominent physical feature of the environment or dominant plant group e.g. stream habitat, fresh water habitat, rotton log habitat, desert habitat, grassland or a pine forest habitat. Thus the habitat of a fish is lake or a stream and that of frog a damp shady place near water bodies. A habitat may be as vast as an ocean or as small as the under-side of a rotton log of a tree or the intestine of the termite. More than one animals or plants may live in a particular habitat.

Biosphere:

Living orgainsms occur all over the surface of planet earth, even in the the most unlikely places. Plants are found at the tops of the world's highest mountains and some animals may occur several kilometers deep on the ocean floor. Within this range from mountain top to ocean floor are found all the living things of our planet earth. Thus life is spread out over the surface of planet earth extending about 5 or 6 miles in the upper limits of atmosphere and about equally far into the depths of the oceans. This life zone at the earth's surface with the air, soil water and other non-living matter that surrounds it, is called the **Biosphere.**

Living organisms are not uniformly distributed on earth. Plants and animals tend to occur in great abundance and variety where them environmental conditions are best for them (e.g., Tropical Rain Forests) because these conditions have an effect on them. In other areas, such as parts of deserts or ice sheets of Antarctic, the only evidence of life to be found is in the form of dormant spores. It is emphasized that plants and animals do not occur by chance throughout the biosphere. Each species has a specific range of geographical distribution occuring only in those areas where environmental conditions are favourable.

ECOSYSTEM

Within a community, living organisms interact with members of their own species and with those of other species. For example, living things which are not able to produce their own food, depend upon other living things for food. Living organisms also interact with their physical environment such as light, temperature and water. This interaction of a community with its environment is an **ecological system or ecosystem.** In this system living things take from the environment materials and energy needed for life. As the organisms use these materials and energy for their growth and development, they give or transfer materials and energy back to the environment on their death and decay. In a normal ecosystem, these materials such as carbon, hydrogen, oxygen, nitrogen and phosphorus etc. are constantly recycled. However, energy cannot be recycled. If an ecosystem is to survive, then the energy must be supplied to it constantly. The source of this energy is the sun. Solar energy maintains the organization of all the ecosystems on planet earth. An ecosystem may be natural as a pond, a lake, a river, an ocean, a forest etc. or artificial (manmade) like an aquarium, a dam, or a cropland. An ecosystem is never static as the organisms living in it are always interacting, not only with one another but with the environment as well.

An ecosystem is never static as the organisms living in it are always interacting, not only with one another but with the environment as well.

Components of the Ecosystem

An ecosystem comprises of two components: **abiotic and biotic.** Both of these contribute equally to the proper functioning of ecosystem.

Abiotic Components	Biotic Components
1. Light	1. Producers: (green plants.)
2. Temperature	2. Consumers: (animals and man.)
3. Water	3. Decomposer or Reducers: (bacteria, actinomycetes, fungi etc.)
4. Atmosphere and Wind	
5. Fire	
6. Soil	
7. Topography	
8. Gravity	
9. Inorganic Nutrients	

These components are discussed below:

A. Abiotic Components

1. Light

Light is the ultimate source of energy for all natural ecosystems, without which no life can exist. During photosynthesis, plants change the light energy into chemical energy in the form of food, subsequently used by all living things. Plant growth and distribution is also affected by the amount of light. Only about two percent of the light reaching the earth is used for photosynthesis and the rest is absorbed by atmosphere, land and oceans and is converted into heat or thermal energy. Thus light energy is also used to maintain the earth's temperature.

2. Temperature

Temperature has also a universal influence in the growth and distribution of animals and plants. Temperature is a measure of intensity of heat in terms of a standarized unit and is commonly expressed as degree either in Fahrenheit °F or Celsius C Heat is a form of energy known as thermal energy. Temperatures vary a great deal on land during different parts of the year and at varying altitudes and latitudes. Such other factors as day and night, amount of precipitation, distance from oceans and presence of forests also play their role in bringing variations in temperature.

Most life in the biosphere functions within a temperature range of 0° to 50°C. Within this range, individual species have minimum, maximum and optimum temperature requirements for their metabolic activities. During high temperatures plants usually remain cool by the loss of water from their bodies by transpiration. Therefore, heat damage occurs only if insufficient water is available for cooling. Most animals cannot tolerate temperature above 45°C although much lower temperatures may also be lethal for species inhabiting cold environments. The low temperatures has harmful affects on the organisms. Most of the plants cease to grow at temperatures below 6°C. Similarly in animals, the rate of metabolic processes decreases with the decrease in temperature of the animal body and the animal becomes slow and lazy.

3. Water

Water is one of the most important factors of ecosystem. It is not equally distributed over planet earth. It is most abundent in aquatic ecosystems and least in deserts. Water circulates throughout the world as water cycle (Fig. 13.1) by precipitation (rain) evaporation and transpiration. Water cycle is not uniform in its rapidity both in time and space. Some parts of earth receive more rain while other areas receive very little. Water is an important factor that determines the quality and quantity of flora and fauna of the biosphere or of an ecosystem. In areas where rain is more, green ecosystems are seen and where rain is less desert ecosystems are encountered. From the ecological point of view, water acts as a limiting factor, the animals and plants have developed morphological and physiological adaptations to face excess or shortage of water. Plants like *Cactus* and *Euphorbia* have thick cuticle and change stored water into mucilage to avoid loss of water. Aquatic organisms, such as fresh water protozoans and bony fishes (both marine and fresh water), have developed various osmoregulatory mechanisms. Amount of water available to animals, also, determine the type of nitrogenous wastes excreted by them. Ammonia, a highly toxic substance needs plenty of water and uric acid, a harmless substance, requires least water for their elimination from the body.

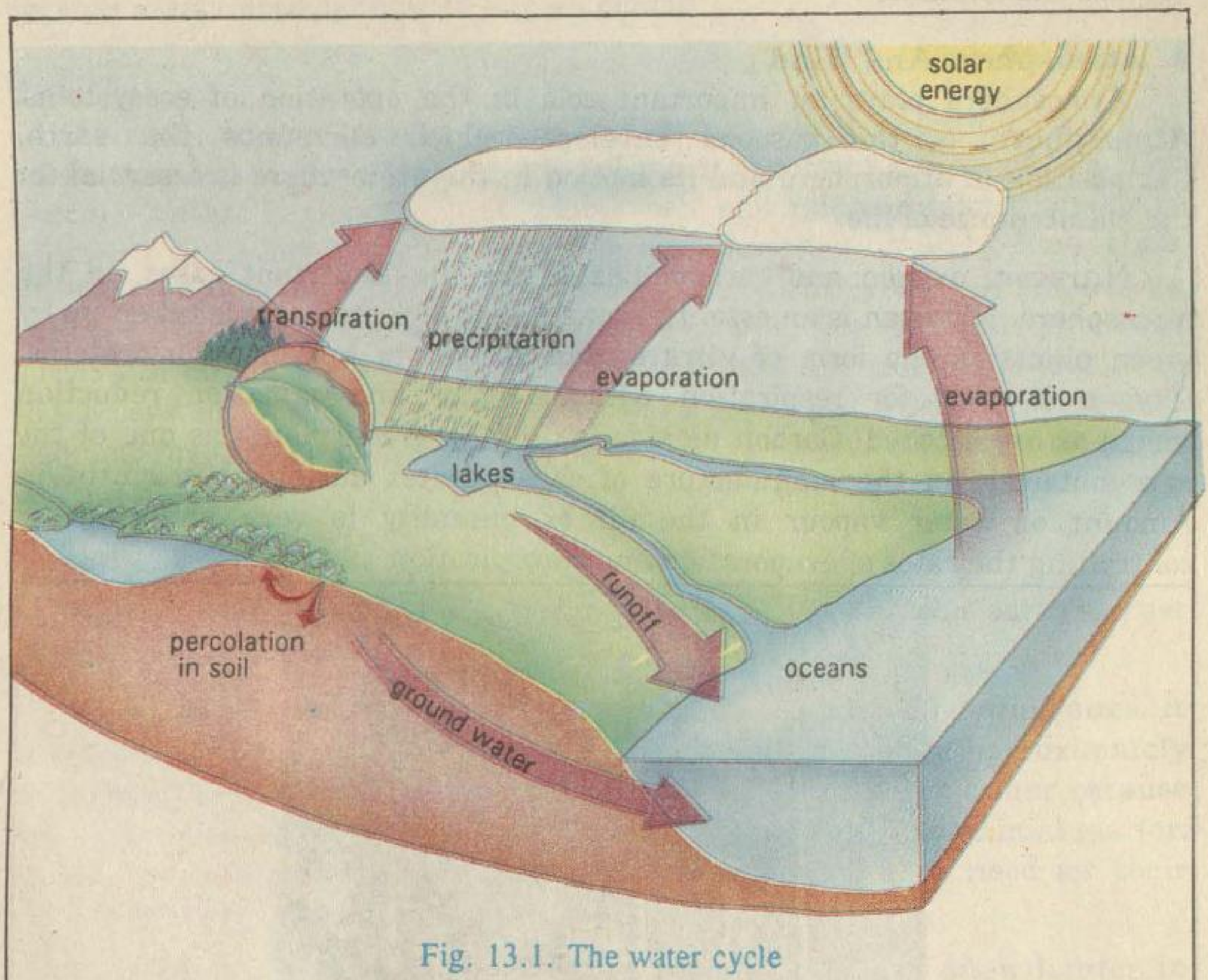

solar energy
transpiration
precipitation
evaporation
evaporation
lakes
runoff
percolation in soil
oceans
ground water

Fig. 13.1. The water cycle

Water freezes at 0°C, becomes, lighter and floats on the surface. Warmer water at 4°C is heaviest and sinks to the bottom. This property of water checks the bottom layers of water in oceans from freezing where most of the organisms live.

Water is the best known solvent and is a relatively stable compound. These two properties of water ensure most chemical reactions within living cells to occur in a controlled fashion.

In animals, the body fluids thicken, as a result of dehydration. Pumping denser blood causes the heart to be strained. Waste products are not diluted adequately and as a result become concentrated in the body. The animal metabolism slows down. Lack of water in homiothermic animals impairs the body's temperature regulating mechanism. In the event, the heat cannot be lost through evaporation, the body temperature will rise and excess heat will damage the animals.

4. Atmosphere And Wind

Atmosphere plays an important role in the operation of ecosystems. **Atmosphere** is the gaseous envelope, which surrounds the earth. Composition of atmosphere and its motion in the atmosphere is essential for the maintenance of life.

Nitrogen, oxygen and carbon dioxide are the important gases, in the atmosphere. Nitrogen is an essential constituent of proteins. It is taken up by green plants in the form of nitrates and is used in building the proteins. Oxygen is vital for respiration without which the oxidation reduction reactions are blocked. Carbon dioxide is used by green plants as one of the raw materials in the manufacture of cabohydrates during photosynthesis. Amount of water vapour in the air or humidity is very important in controlling the rates of evaporation and transpiration.

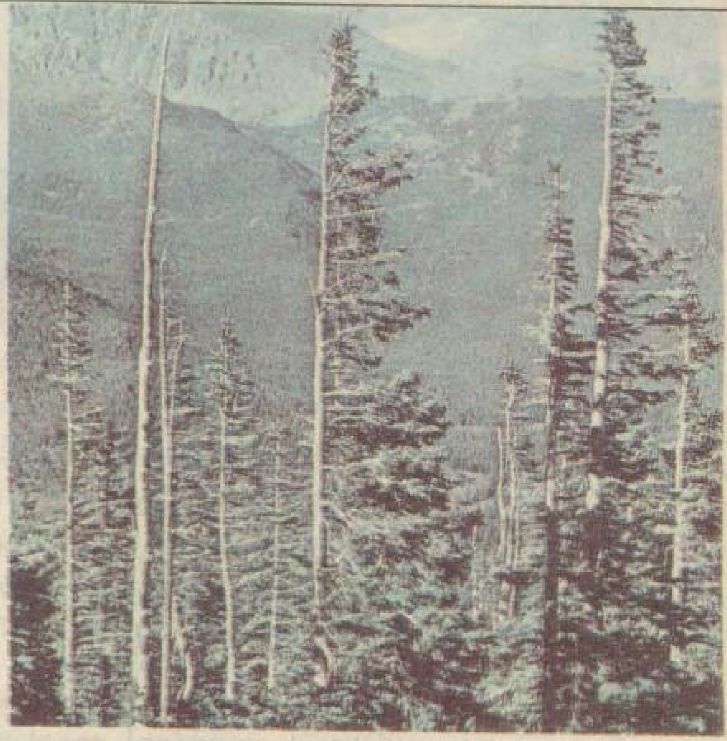


Fig. 13.2. These Pine trees have been damaged by the winds to form Flagform trees.

Atmosphere (air) in motion is **wind.** **Strong winds at high altitude and in plains can damage plant buds, cause breakage of branches and even uprooting of plants. In high mountains some plants may develop 'flagform' or one sided** trees under the influence of strong winds (Fig. 13.2). The decreased atmospheric pressure at high altitudes affects the distribution of mammals because of its relationship with oxygen deficit.

5. Fire

Fire is another abiotic factor that brings about sudden changes in ecosystem. Man and lightening are the most important causes of fire. Dry organic matter is changed into soluble ash and releases many important nutrients for rapid recycling which stimulates plant growth. Rich plant growth results in the increase of herbivores populations in the area followed by the carnivores. In areas where fires are frequent, fire resistant organisms survive in larger numbers than fire sensitive ones and this tends to change the ecosystem of that region. Plants have developed adaptations to face frequent fires. Some plants have developed fire resistant underground stems and buds.

6. Soil

Soil can be defined as the upper weathered layer of the earth's crust affected by plants and animals.

Top soil is the surface soil. It consists of soil particles of varying sizes. It is inhabited by plant roots and other living organisms. It is approximately 10–20 centimeters in thickness and is generally dark brown in colour because it contains humus - a product formed by the decay of plant and animal matter. It also contains many chemical substances which the plants need for their growth and development.

Subsoil is a wider zone lying below the topsoil. It is often lighter in colour than the top soil and is mostly composed of large soil particles and stones.

Soil plays vital role in supporting life on land. Land plants depend directly on soil to be anchored firmly to maintain their position and to withstand pressure from strong winds. The soil also provides water to plants in adequate amount alongwith organic and inorganic nutrients. It provides air for the respiration of plant roots as well.

7. Topography

Topography refers to the description of land, its altitude, steepness and direction of slope. Topography has no direct influence on the organisms but acts through the modification of other physical factors of the environment such as atmosphere, radiation, temperature and moisture content.

Increasing altitudes lead to increase in radiation and higher wind velocities but lower temperatures. There is greater rainfall associated with higher humidity at high altitudes as compared to the low ones as in Murree hills. Atmospheric pressure decreases with decreasing altitude producing changes in the structure and distribution of organisms. The steepness of slope affects drainage and stability of soil. Steeper slopes on account of more drainage, are comparatively dry and support fewer communities as compared to less steep slopes.

8. Gravity

Gravity is the most constant of the abiotic factors of environment and has the least influence on the biological world. It acts as an external stimulus in the growth responses of plants. It has effect on the growth of roots and shoots. Roots grow towards gravity where as shoot grows away from it.

Objects are pulled towards gravity and organisms need much energy to move against it. Certain structural adaptations found in animals and plants help them to overcome the pull of gravity. Striking examples of such adaptations are the development of xylem in plants and wings in animals.

9. Inorganic Nutrients

These include compounds such as nitrates, phosphates and salts of calcium, magnesium, oxygen, calcium, nitrogen and other elements etc. A small portion of these is in solution and is readily available to living organisms but a much larger portion is held in reserve in the form of sediments or solids. The rate of release of these substances is one of the most important processes which regulates the rate of function of the whole ecosystem.

B. Biotic Components:

On the basis of their function, the biotic components are as follows:

1. The Producers
2. The Consumers
3. The Decomposers

1. Producers

Producers in an ecosystem are represented primarily by green plants which are capable of producing their own food. Because they nourish themselves they are known as **auto-troph.** The green plants may be rooted in the soil or may exist as minute floating plants called **phytoplankton.** Phyto means 'plant' and Plankton means 'floating'. Rooted plants are producers of terrestrial habitat while phytoplankton are aquatic and more important than rooted plants in aquatic habitats.

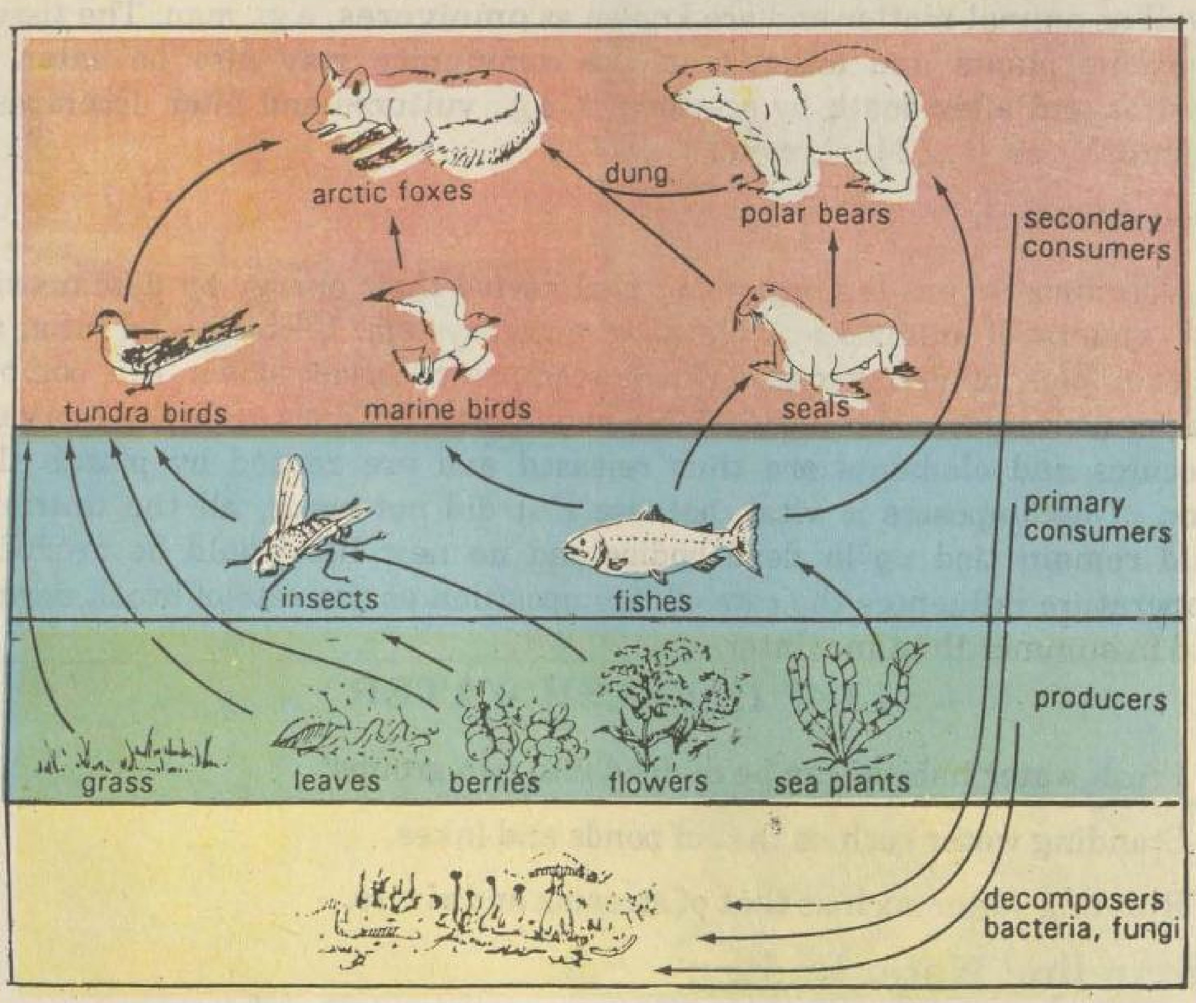

arctic foxes
dung
polar bears
secondary consumers
tundra birds
marine birds
seals
insects
fishes
primary consumers
producers
grass
leaves
berries
flowers
sea plants
decomposers bacteria, fungi

Fig. 13.3. Trophic levels

Green plants use sunlight for the manufacture of carbohydrates. A part of the manufactured food is utilized by the plants themselves, while the excess materials and the plant protoplasm is utilized by the consumers and decomposers.

2. Consumers

These are mostly animals which obtain their food by eating plants and other animals, because of this they are known as **heterotrophs.** The **primary consumers** *e.g.,* rabbits are the herbivores that feed directly on green plants. The principal primary consumers in the terrestrial habitats are insects, rodents and ruminants and in the aquatic habitats are small crustaceans, molluscs and some fishes. The **secondary consumers** *e.g.*, dog feeds on herbivores. The herbivores serve as food for primary carnivores, these in turn may fall prey to secondary carnivores. Some animals eat plant as well as animal matter and are known as **omnivores**, e.g., man. The tissues of various plants and animals in the community may also be eaten by parasites and after death by scavengers, *e.g.*, vultures and later decomposed by saprophytes. (*i.e.*, Mushroom).

3. Decomposers

Decomposers are the organisms that derive their energy by decomposing dead remains of animals and plants in an ecosystem. Bacteria and fungi are the examples of decomposers. The decomposers break down the complex organic molecules manufactured by plants and animals. Simple inorganic molecules and elements are thus released and are reused by plants. The action of decomposers is vital, because if it did not occur, all the nutrients would remain tied up in dead bodies and no new life would be produced. Temperature influences the rate of decomposition as the rate of break down is rapid in summer than in winter,

LIFE IN FRESH WATER

Fresh water habitat can be divided into two groups:

(A) Standing water such as that of ponds and lakes.

(B) Running water such as that of streams and rivers.

A. Standing Water Bodies:

Standing water bodies are composed of three zones:

- *(a)* Littoral zone.
- *(b)* Limnetic zone.
- *(c)* Profundal zone.

(a) Life in the Littoral Zone

Littoral Zone is the shallow water region near the shore with light penetrating to the bottom. Aquatic life is most conspicuous in this zone, where the plant communities (producers) form concentric rings around the pond or lake as the depth increases (Fig. 13.4 and 13.5)

The outermost ring is that of the emergent plants like Typha, and Sagitarria. They are firmly rooted in water but their shoots remain out of water. These are followed by rooted plants with floating leaves, such as

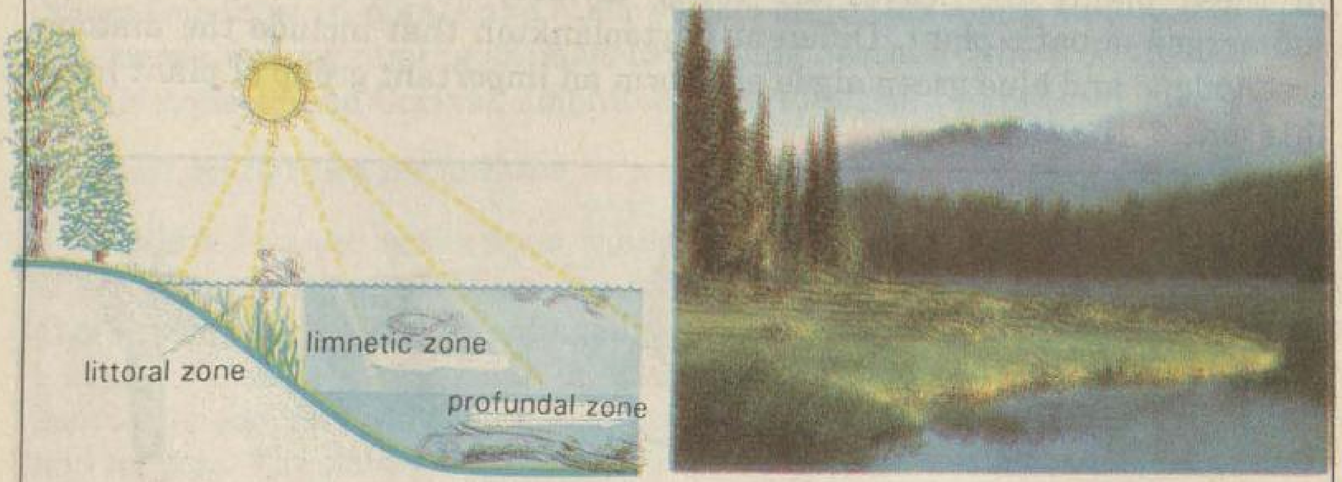

littoral zone
limnetic zone
profundal zone

Fig. 13.4. Major habitat zones of a lake

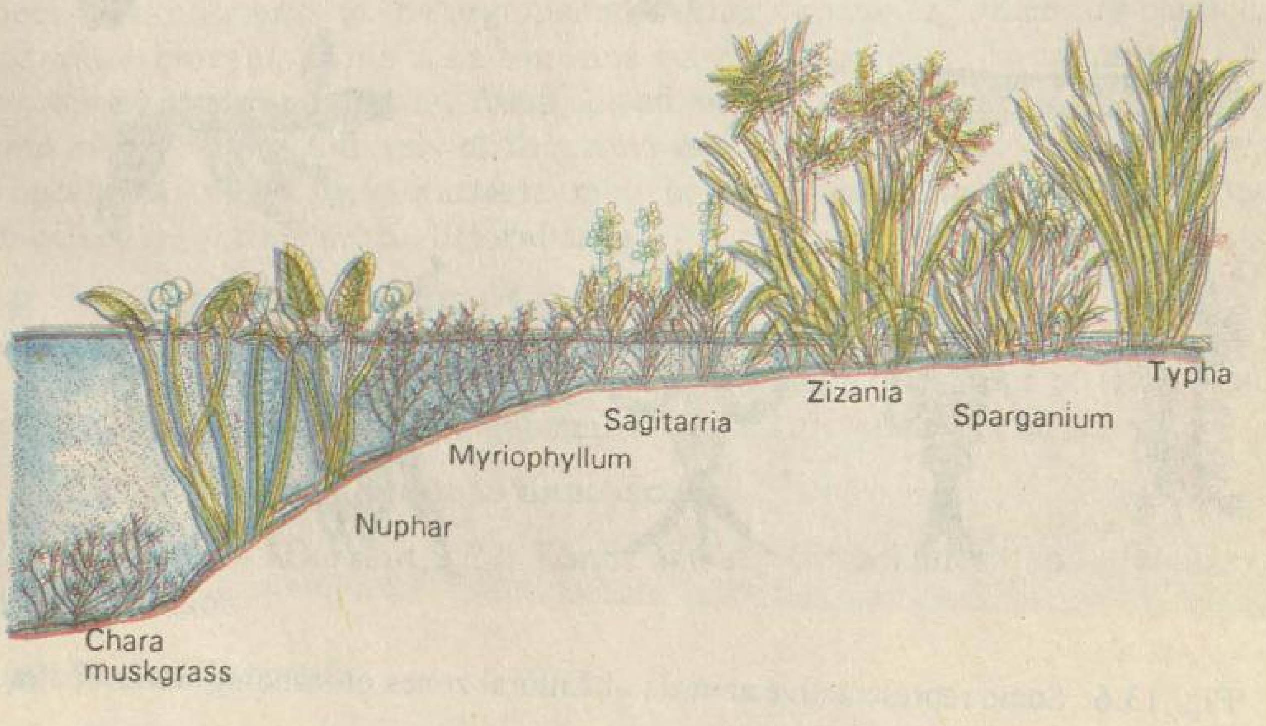

Chara
muskgrass
Nuphar
Myriophyllum
Sagitarria
Zizania
Sparganium
Typha

Fig. 13.5. Zonation of vegetation in Littoral zone.

Nuphar (Water lily); deeper still are the thin stemmed water weeds, rooted but totally submerged, such as Chara (Musk grass), Vallisneria and Hydrilla. In these plants the leaves are finely divided, an obvious adaptation of submerged aquatic plant. Different phytoplankton that include the diatoms, green algae and blue green algae also form an important group of plant life in this zone.

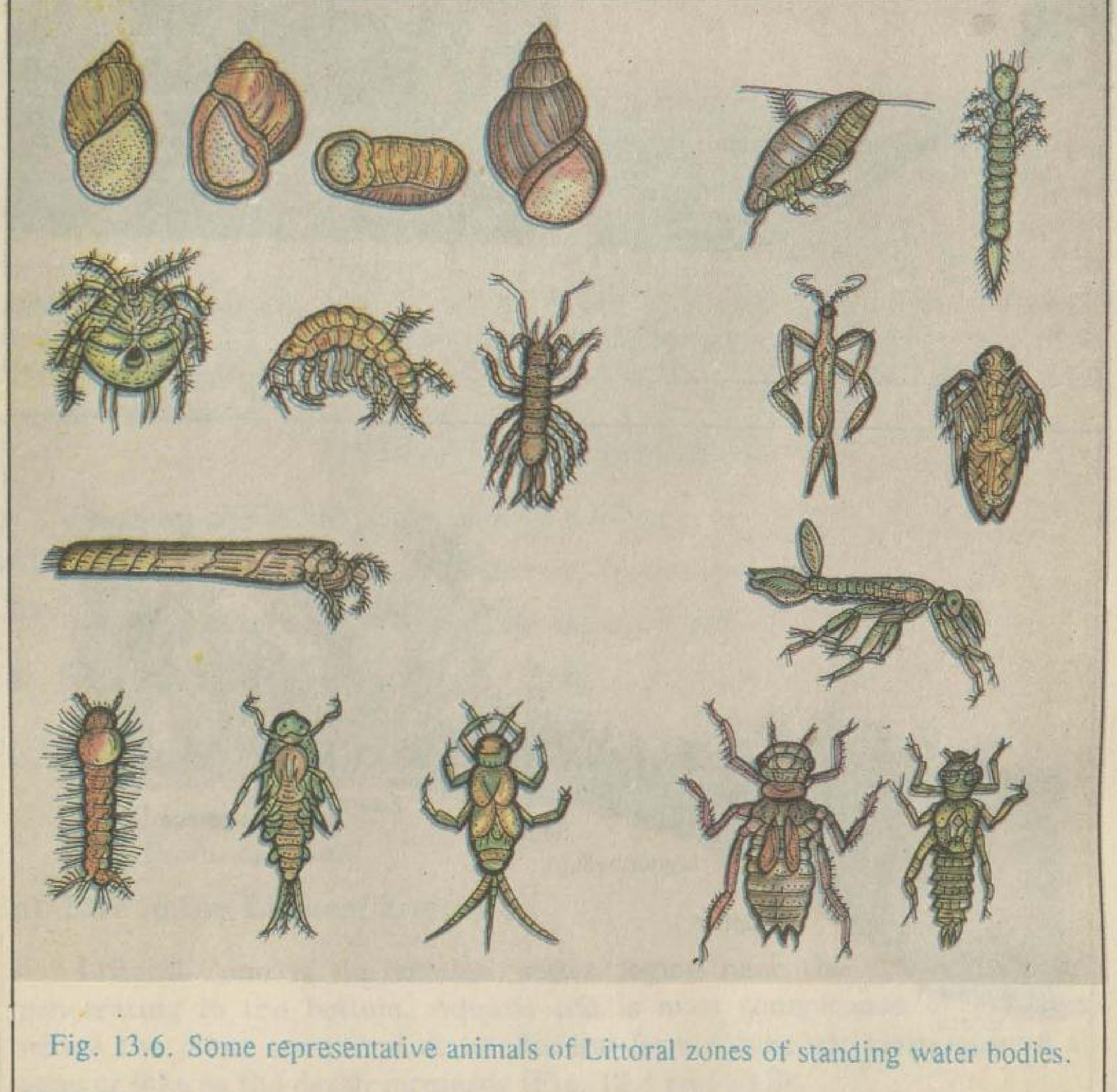


Fig. 13.6. Some representative animals of Littoral zones of standing water bodies.

A much greater variety of animals (consumers) occurs in the littoral zone as compared with the other two zones. At the bottom are various nymphs of some insects, cray fish, isopods, worms, snails and clams (Fig. 13.6). Other animals like some insect nymphs, flat worms, hydras, snails, zooplankton and others live in or on plants and other objects projecting above from the bottom. The larger free swimming animals like diving beetles (Cybister), various bugs like (Notonecta and Corixa), amphibians, tortoises and snakes are also found.

(b) Life in the Limnetic Zone

Limnetic zone is the open water zone away from the shore to the depth of effective light penetration and is occupied by phytoplankton like green algae, blue green algae, dinoflagellates, euglena and volvox. A characteristic feature of these organisms is the marked seasonal variation in their population density. Limnetic zooplankton include a few crustacean species and rotifers. The fishes are found entirely in free swimming zone.

(c) Life in Profundal Zone:

Profundal zone is the zone of deep water under the limnetic zone. This is beyond the reach of light penetration. This zone is obviously absent in ponds and shallow lakes. Profundal zone is a dark zone and thus its inhabitants depend for food on littoral and limnetic zones: In return this zone provides the necessary nutrients to the organisms of other two zones, which are carried up by water currents. This zone contains very few species. The community here is represented by bacteria, fungi, blood worms (chironomid larvae) annelids and small clams. Animals of this zone are adapted to periods of low oxygen concentration, whereas bacteria may be anaerobic. Many pond fish spend much of their time in the littoral zone.

B. Running Water Bodies:

Moving waters differ in a number of respects from that of the standing waters and these differences determine the nature of life found therein.

The differences are due to three factors:

(a) Water Current, *(b)* Land Water Interchange and *(c)* Oxygen Concentration.

(a) Water Current:

The velocity of water current vary greatly in different parts of the same stream at different times. The velocity of the current is determined by the steapness of the gradient, the roughness and width of the stream bed.

(b) Land Water Interchange:

The streams are more closely associated with the surrounding land because in the case of streams, land-water junction is larger than that of the standing waters. Although streams have their own producers but they are insufficient to support large number of consumers found therein. On account of shallowness the temperature of water in stream shows wider fluctuation as compared to the standing water habitats. There is a thorough mixing. Therefore, the temperatures and concentration of dissolved substances are usually the same from top to the bottom.

(c) Oxygen Concentration:

Water in streams is usually shallow and has large exposed surface and is in constant motion. These three factors result in uniform distribution and abundant supply of oxygen even in the absence of green plants. For this reason stream animals generally have narrow range of tolerance and are especially susceptible to reduced oxygen level. Stream communities are, therefore, very sensitive to organic pollution causing reduction in the oxygen supply.

Two habitat forms are generally recognized in lotic water namely *(i)* the rapids and *(ii)* the pools.

(i) Life in rapids: Current is the major limiting factor in the rapids and the composition of communities in the rapid is different from those of the quiet waters of ponds and lakes. Thus the typical stream community is considered to be characteristic of the rapids.

Bottom living invertebrates are more abundant in rapids and show adaptations for maintaining a fixed position in swift water. These adaptations may be in the form of possession of hooks and suckers, the sticky under surface etc. Some of the producers found are green algae (Cladophora), diatoms and mosses. Amongst the consumers are sponges, cadfish, fly larvae, certain insects, flat worms, snails etc.

(ii) Life in pools: Nekton and burrowing animals are more abundant in the pools than in rapids.

LIFE IN OCEANS

Ocean is not only considered the cradle of life but is also the greatest reservoir of life itself. Oceans are divided into different zones and regions which differ from one another in the amount of nutrients, oxygen, temperature, depth and light penetration. Accordingly the organisms found in each zone differ in form and population density.

Marine animals include representatives of all phyla and classes except the centipedes, millipedes, onychophora and amphibians. The ctenophores, brachiopods, chaetognaths, echinoderms, and lower chordates are exclusively marine. Species and individuals are most abundant near the surface and decrease with increasing depth.

Life Zones in the Oceans

Broadly speaking ocean is divided ecologically into two life zones:

(a) Pelagic Zone.
(b) Benthic Zone.

Life in Pelagic Zone:

Pelagic zone consists of open waters above the sloping ocean floor and the bottom of the sea. It is shallow near the sea shore but gradually becomes deeper as one moves away from the shore. (Fig. 13.7).

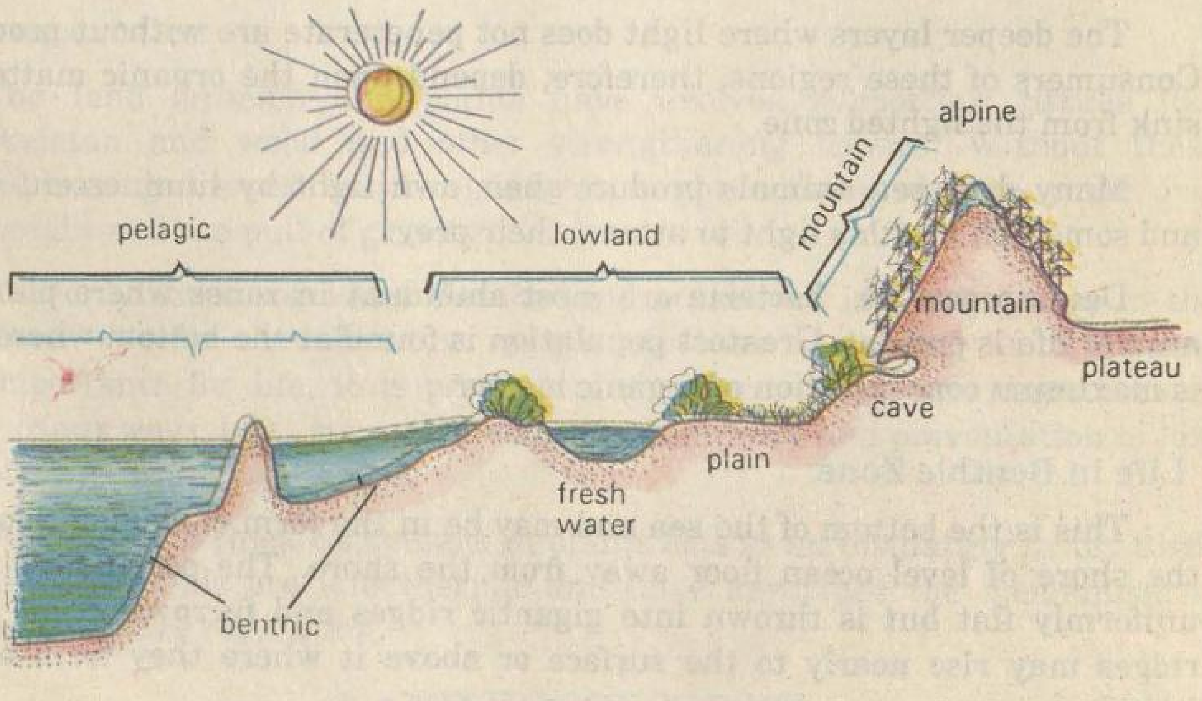


Fig. 13.7. Zonation in the sea, low land and mountain

The producers of the pelagic zone are the Phytoplankton. Diatoms and dinoflagellates are most abundant. Near the sea shore, where the water is shallow and light peneteration effective, sea weeds are also found. Sea weeds belong to green algae, brown algae and red algae and are distributed from shallow to deeper waters respectively. In the deeper and lighted regions of this zone, especially in areas of upwelling (upwelling — a process by which nutreint rich deep water is brought to the surface), dense populations of diatoms and dinoflagellates may be found.

The consumers of the pelagic zone are the zooplankton and other active swimmers. Zooplankton include protozoa, jelly fish, minute worms, copipods, some molluscs, echinoderms and larval fish. Zooplankton of the deeper parts of the pelagic zone includes only those forms which retain planktonic character through out their life like protozoa, jelly fish, minute worm and copipods. Amongst the actively mobile consumers are the molluscs like cuttle fish, squids and many other fishes. Very actively mobile animals are found in the deeper parts of the zone. Commercial fish like herring, oceanic birds, sharks and whales are also found. Amongst the air breathing vertebrates whales are completely independent of land.

The deeper layers where light does not peneterate are without producers. Consumers of these regions, therefore, depend upon the organic matter that sink from the lighted zone.

Many deep sea animals produce their own light by luminescent organs and some fish use this light to attract their prey.

Decomposers *i.e.,* bacteria are most abundant in zones where plant and animal life is present. Greatest population is found at the bottom where there is maximum concentration of organic matter.

Life in Benthic Zone:

This is the bottom of the sea and may be in the form of sloping floor near the shore of level ocean floor away from the shore. The ocean floor is not uniformly flat but is thrown into gigantic ridges and furrows. Some of the ridges may rise nearly to the surface or above it where they form oceanic islands.

Near the sea shore, in the region of effective light penetration, sea weeds of different types may be present encrusted to the bottom. Most of the benthic zone, being very deep, is in perpetual darkness and, therefore, no producers are found there.

Consumers of this zone may include sedentry forms like oysters, feather stars etc, freely mobile but relatively inactive formslike mussels, echinoderms etc, and very active forms like crustacea, molluscs and fish. Actively swimming animals may also wonder as pelagic forms.

Very high populations of bacteria, (decomposers), are found at the bottom which decompose sinking corpses from the light zone.

LIFE ON LAND

In contrast to aquatic habitat, land habitat is harsh for the organisms to inhibit. There are three aspects of the harshness of the land habitat which the organism have to face. These are:

1. Thinness of the atmosphere and pull of gravity.
2. Limited water supply.
3. Variations in temperature.

These problems are solved by land organisms by the development of certain characteristics.

Characteristics:

a) The land animals and plants have evolved supporting tissues like skeleton and wood and other strengthening tissues. Without these supporting tissues, land organisms might collapse due to their own weight and the pull of gravity.

b) The only source of water for the land organisms is precipitation in the form of rain though in a meagre amount. As water is of utmost importance for life, it is procured and conserved by land organisms in various ways. (*e.g.,* storage of water in their body and preventation of loss of water from plant body).

c) Formation of thick corky bark in plants acts as an insulating layer. Birds and mammals are endothermic and have developed the mechanism of temperature regulation.

LAND ECOSYSTEMS

Following main types of the land ecosystems are recognized (Fig. 13.8).

I. Forest Ecosystem.
II. Grassland Ecosystem.

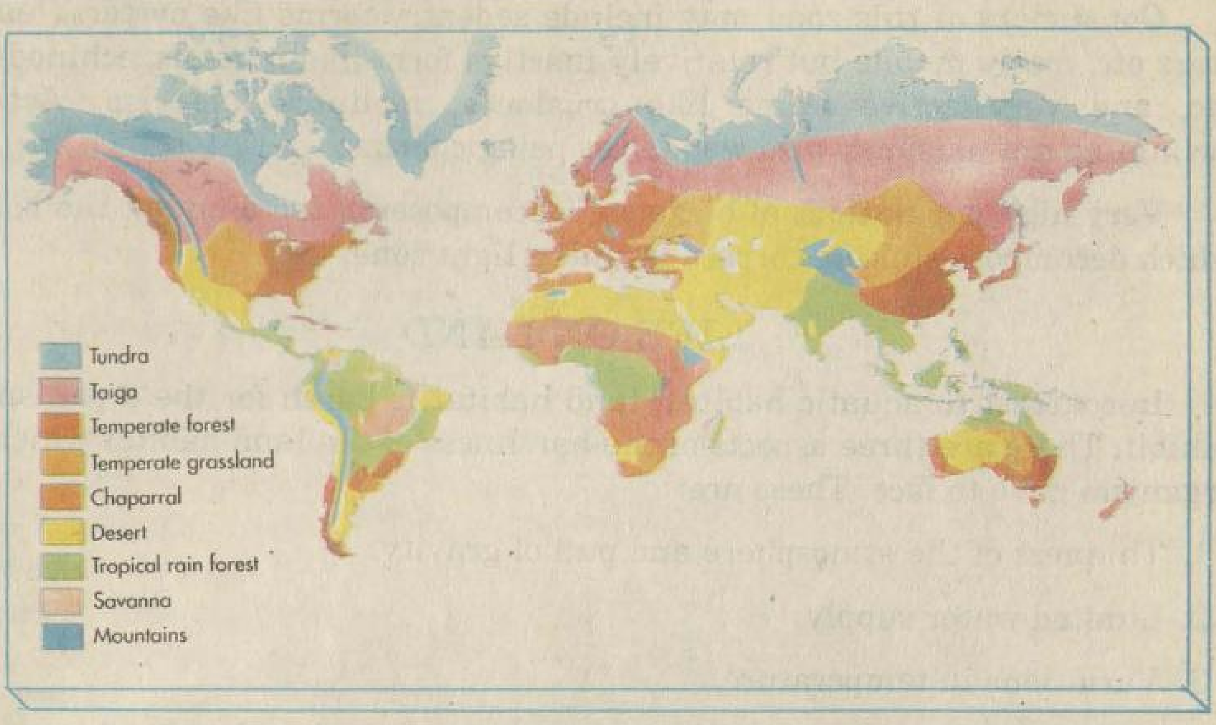

Tundra
Taiga
Temperate forest
Temperate grassland
Chaparral
Desert
Tropical rain forest
Savanna
Mountains

Fig 13.8. Biomes of the world

III. Savana Ecosystem.
IV. Desert Ecosystem.
V. Tundra Ecosystem.

I. Forest Ecosystems

Major forest ecosystems of the world include:

a. Tropical Rain Forests
b. Temperate Deciduous Forests
c. Coniferous Alpine and Boreal Forests

These three types are breifly discribed as under:

a) Tropical Rain Forests

In tropical rain forests, rainfall is abundant, all the year round. Annual rainfall exceeds 2000 mm. Temperatures in general remain high and nearly constant through out the year (Fig. 13.9 and Fig. 13.10). Vegetation is extremely dense.

These forests occur between tropics of cancer and capricorn. The forests are characterised dur to richness and diversity of life. There is a great variety of trees in some part of Brazilian rain forests. There are as many as 300 species of trees in 2 sq. km. Jungles are thick, and impenetrable. The competition

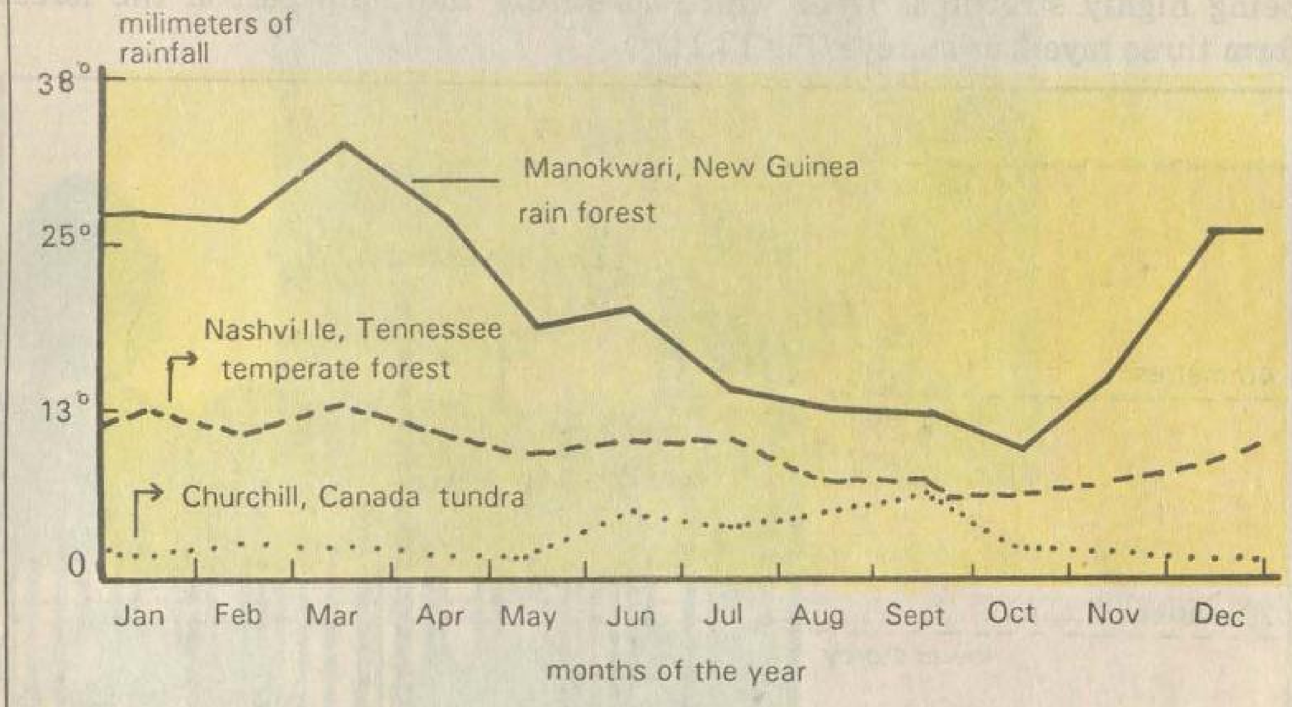


Fig 13.9. Average monthly variation in Rainfall at three selected locations (tundra, temperate forest and tropical rain forest)

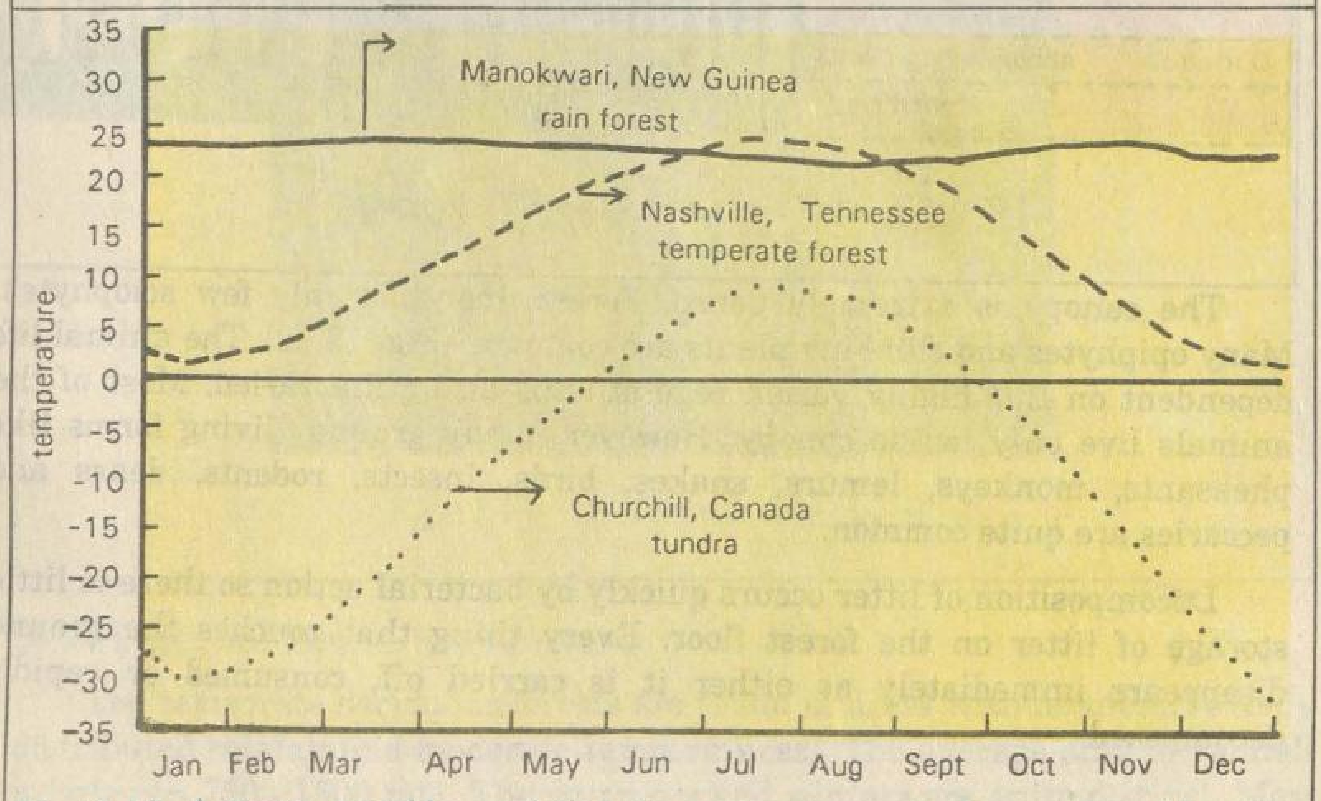


Fig 13.10. Average monthly variation in temperature at three selected locations (tundra, temperate forest and tropical rain forest)

among plants of the tropical rain forest for light has resulted in the forest being highly stratified. Trees which constitute the main part of the forest form three layers or storeys (Fig.13.11).

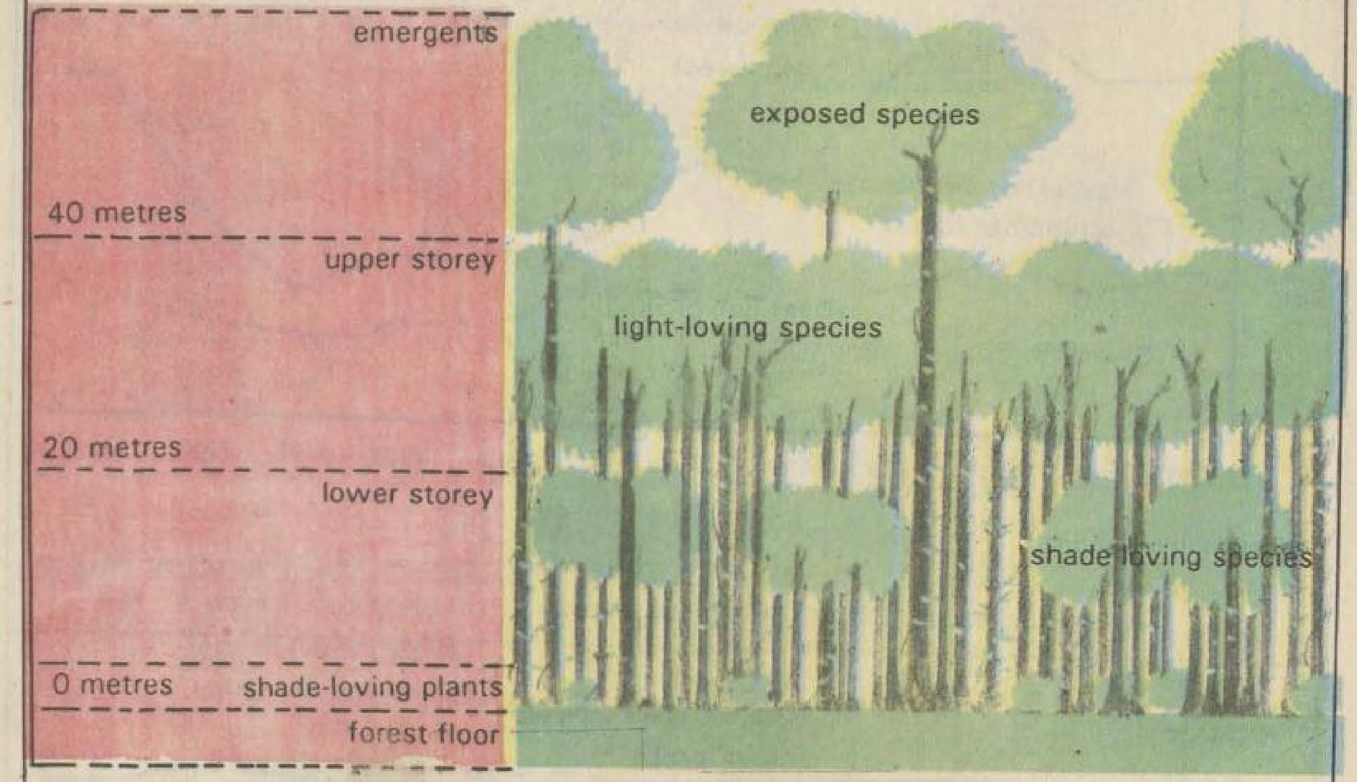

emergents
exposed species
40 metres
upper storey
light-loving species
20 metres
lower storey
shade-loving species
0 metres
shade-loving plants
forest floor

Fig 13.11. Profile of a tropical Rain Forest

The canopy is extremely dense. Forest floor has only few sciophytes. Many epiphytes and climbing plants are common. (Fig. 13.12). The animal life dependent on this highly varied vegetation is also quite varied. Most of the animals live only in the canopy. However, many ground living forms like pheasants, monkeys, lemurs, snakes, birds, insects, rodents, dears and peccaries are quite common.

Decomposition of litter occurs quickly by bacterial action so there is little storage of litter on the forest floor. Every thing that touches the ground disappears immediately as either it is carried off, consumed or rapidly decomposed.

Fig. 13.12. Epiphytes — winners in the competition for sunlight.

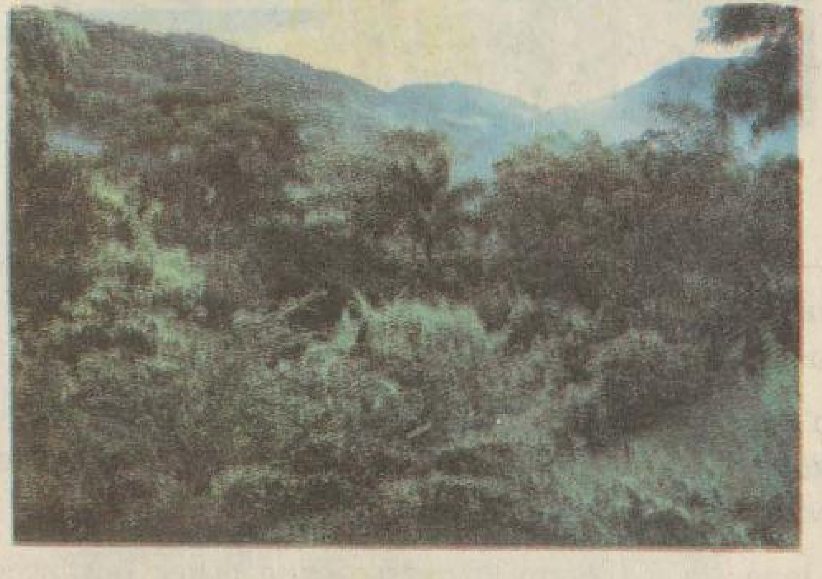


Fig 13.13. A Tropical rain forest.

b) Temperate Deciduous Forests

The temperate deciduous forests are found in areas with abundant evenly distributed rainfall and moderate temperatures. The average annual rainfall is between 750 - 1500 mm. The summers and winters are quite distinct. Most areas of temperate deciduous forests have been modified by human activity.

These forests originally covered eastern North America, Europe, parts of Japan, China, Australia and southern parts of South America.

The dominant trees of the temperate deciduous forests depending largely on local rainfall, vary from region to region. Temperate moist conditions prevail in Shogran and Neelam valley of Azad Kashmir in Pakistan. *Taxus baccata, Pinus wallichiana* and *Berberis lycium* are the prominent trees found here. The stratification is distinct and four layers in the forests are recognized (Fig. 13.14).

Fig 13.14. Temperate forest

1. The tree layer where the crowns of trees form a continuous canopy. The trees are usually 8 to 30 m tall.
2. The shrub layer, which grows to a height of 5m. The shrubs and bushes are also woody like trees but branch at a much lower level, closer to the ground and form a discontinuous storey.
3. The field layer is made up of grasses and other herbaceous plants and ferns.
4. The forest floor forms the fourth layer. Here mosses, liverworts and lichens are found. It is also often covered with a layer of litter.

The soil is rich and fertile and greyish brown in colour. In addition to the usual constituents of soil it contains decomposing organic matter consisting of decaying plant and animal remains inter mixed with bacteria, protozoans, fungi, arthropods and worms that thrive on dead organic matter. Decaying organic matter, dead roots, the burrowing earth worms and other animals make the soil porous which increase the water holding capacity of the soil. Animal life from moist temperate regions of Shogran and Neelam Valley in Pakistan are *Solenorotos tibitanus* (black bear), *Felis bengalensis* (leopard cat) and *Macaca mulatta* (rhesus monkey).

c) Coniferous Alpine and Boreal Forests

Coniferous forests located at high altitude are called **alpine** while those located at high latitude are called as **boreal.** Both are similar in physiognomy and climatic conditions. The dominant plants are Pines, Abies and Cederous etc.

The coniferous forests stretch across both North America and Eurasia

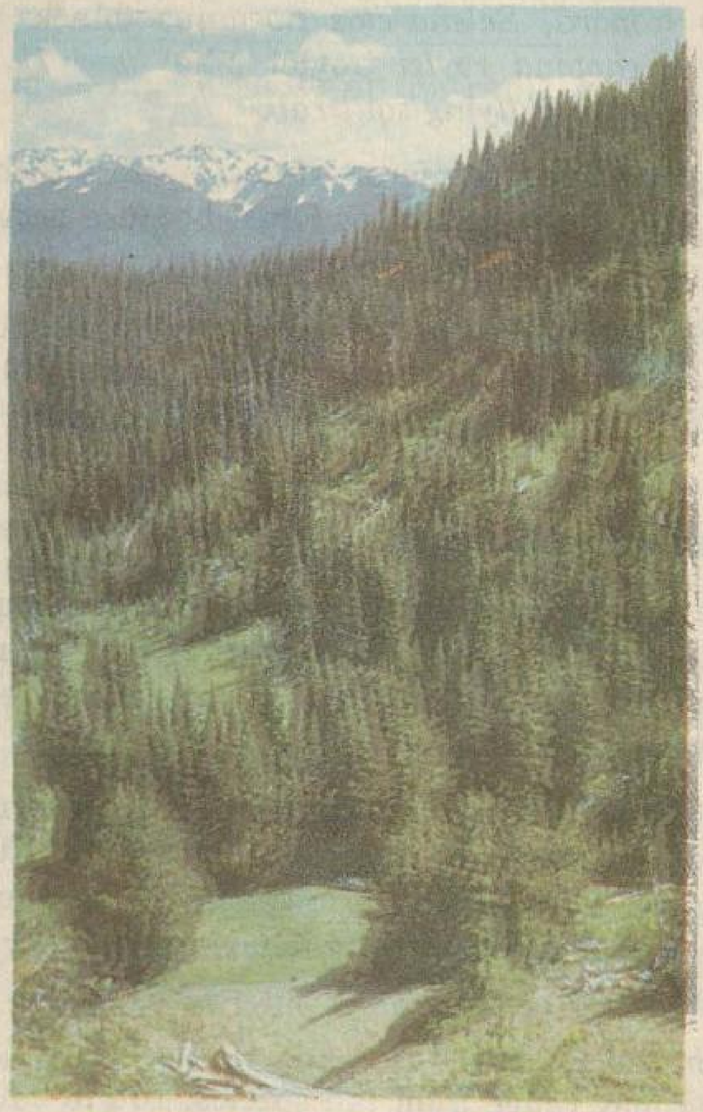


Fig 13.15. Coniferous forest

just south of the tundra and is characterized by long severe winters and a constant cover of winter snow. (Fig. 13.15). The temperatures may be as low as 10°C. The growing season shrinks to 3 or 4 months as compared to temperate deciduous forests. In the coniferous forests at high altitudes in northern mountain regions of Pakistan like upper reaches of Kaghan, Jaba Valley in Swat, Dir and Chilas, the climate becomes dry as compared to Kaghan Valley in Pakistan and Neelam Valley in Azad Kashmir. Characteristic plants and animals of these forests are:

Plants:

Abies pindrow, Pinus roxburgii, Pinus wallichiana, Picea smithiana and Cederous deodara.

Animals:

Snow leopard, Selenarctos tibetanus (black bear), *Morcopolo sheep, Ochotona roylei* (roylei pika) *and Hylopetes fimriatus* (small Kashmir *flying squirral).*

The ground layer of the coniferous forest is less richly populated by invertebrates than that of the deciduous forest because accumulated litter is slow to decompose.

Larger animals like moose, caribou and snowshoe hare feed on foliage. Carnivores like wolf and lynx often feed on small mammals and travel long distances in search of prey. Seed eating animals like squirrels and crossbills are also found.

II. The Grassland Ecosystem

The grasslands are found where annual rainfall is about 250 to 270mm, not enough to support a forest. For the growth of a forest reliability of rain fall is more important than the amount. The grasslands are characterised by periodic and often severe droughts.

Grasslands are found in temperate climates in the interiors of continents. Prairies of N. America, Pampas of Argentina, Steppes of Russia and Veld of S. Africa are all grass lands. These grasslands do not have woody plants. (Fig. 13.16). However, grasslands in tropics having clumps of woody trees are known as **Savanna.**

Depending upon the amount of rain fall, the species of grasses present in any given grassland may range from tall species, 150 to 250 cm in height, to short species of grass that do not exceed 15 cm in height. The soil of grass

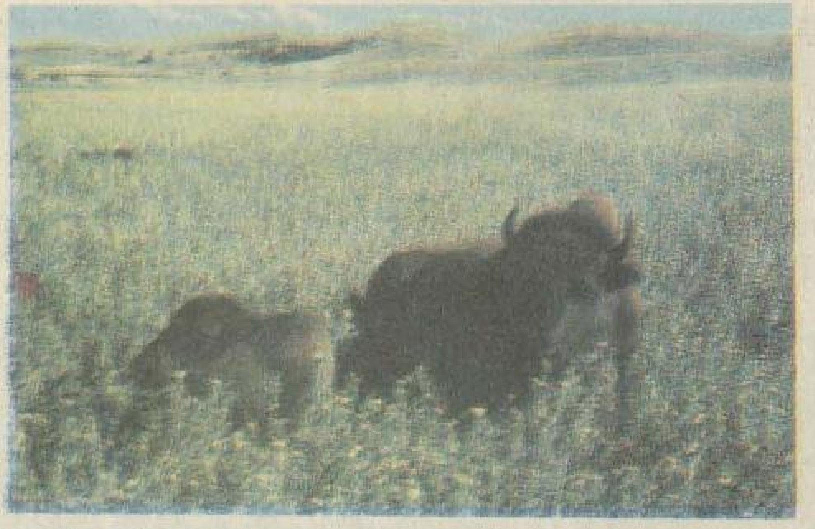


Fig 13.16. Grassland with a herd of bison.

lands is very rich in humus because of the rapid growth and decay of the individual plants.

Grasslands are areas of stress for the animals as no shade and protection from sun and winds is available. In the absence of trees, grasslands are subjected to greater variation of temperature, moisture, winds and intensity of sunlight and as such there are fewer hiding places of for animals. Many grassland animals are fast runners or burrowing forms. Burrows act as refuges during periods of intense heat and form attacks of predators.

Large mammals like bison, antelope, zebras, wild horses and amongst the birds ostrich are very swift on foot. Small burrowing birds like prairie chickens, meadow larks etc. and some reptiles are also found. Predators of grassland include coyotes foxes, badgers and rodent eating hawks. Grasslands in Pakistan are found in the northern mountain ranges such as lower Chitral, parts of Gilgit and Kashmir, Waziristan and north Kallat. The rains here are heavier than ordinary grassland.

III. Savanna Ecosystem

Savanna is a term applied to any tropical vegetation ranging from pure grassland to woodland with much grass. Another important character is that tropical grass is much taller than tamperate grasses and may be upto three and a half metres. It covers wide belt on either side of equator with a very warm and very dry climate and is common in South Africa, Southern Asia and India. Most savannas are the result of climate conditions, however, some have been created by the destruction or opening up of tropical rain forests.

There is great variety of trees. Acacias are common. Dominant animals are large grazing mammals like zebras, large carnivores as lions and tigers are also met with.

Productivity is less than tropical rain forest. Water is a limiting factor. Man has tremendously affected savanna through agriculture, hunting and fire (Fig. 13.17).

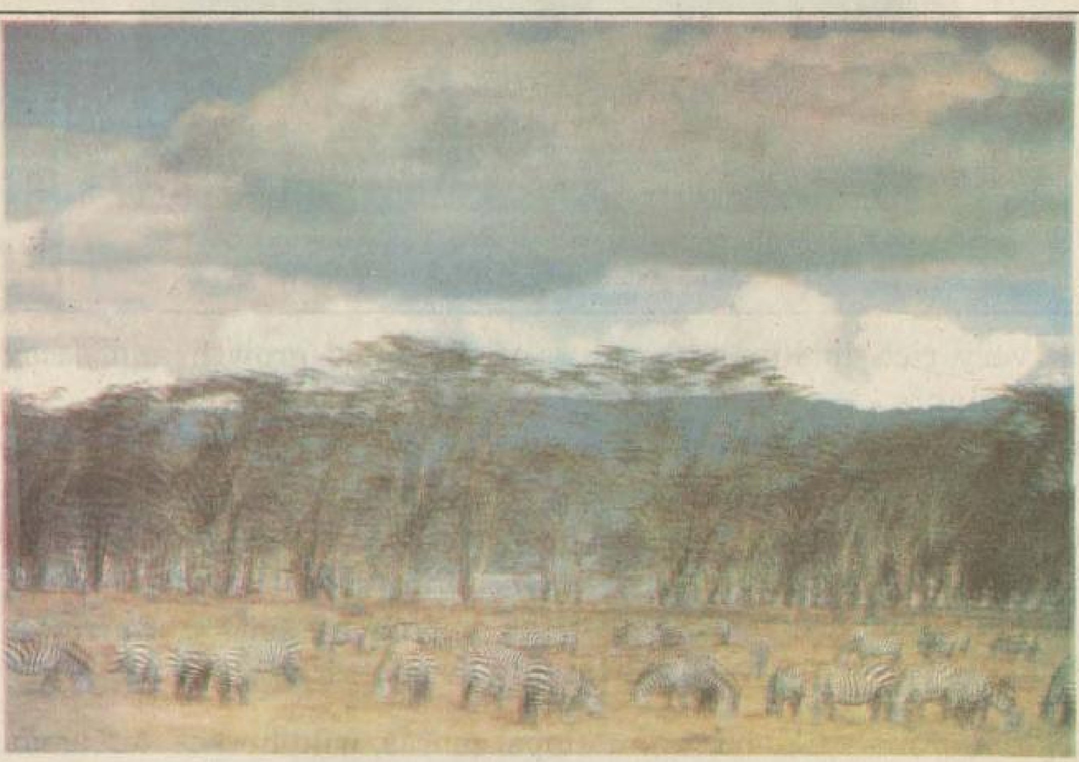


Fig. 13. 17. The savanna

IV. Desert Ecosystem

Deserts generally occur in regions where annual rainfall is less than 250mm and even this meagre amount is unreliable and unevenly distributed. There may be frequent rains during one particular year but then many years may go completely dry e.g., the 'Thar' desert in Pakistan. In the absence of sufficient precipitation, the plants are widely spaced. In the absence of thick vegetation, run off is rapid, and whatever little rain does fall is not available as it would be in a grassland or forest. Consequently there is little loss of water vapour into the air either by evaporation or by transpiration, so the humidity is always low. As a result of dry air, the variation between day and night temperatures, may be as great as 56°C. In the absence of any barriers the strong winds cause damage to plants.

Scarcity of water has made plants and animals to develop special morphological and physiological adaptations to enable them to obtain and conserve whatever water is available.

Some desert plants have shallow root systems that spread below the surface of soil. These plants are known as **surface feeders.** They absorb water very quickly before it is evaporated. Some other desert plants have deep roots and absorb water from the deeper layers of the soil. These are known as **deep feeders.** The individual plants, in the desert, are widely spaced with large bare areas separating them. Water is conserved by desert plants, in a variety of ways. Cacti and Euphorbias have fleshy stems in which water is stored for use during periods of drought. (Fig. 13.18).

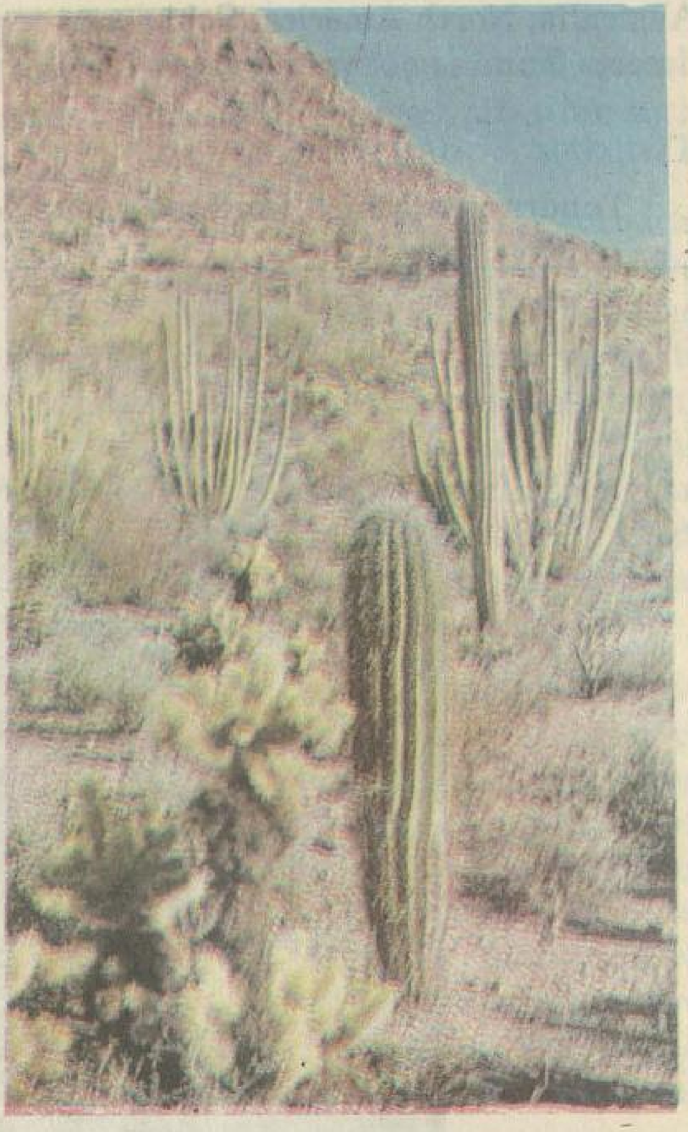


Fig 13.18. Euphorbia — desert plant.

Animals also show morphological, physiological and behavioural adaptations for conserving water. Many animals live in burrows where humidity is higher and temperature lower than that of outside the burrow. Many animals are nocturnal which is a means to avoid intense heat. Desert animals have the ability to pull on with much less water. Many do not drink water and rely on the water present in their succulent foods like cactus plant. Some desert animals like reptiles and insects excrete nitrogenous wastes in the form of uric acid which requires very little water for its removal. A few species of mammals have become secondarily adapted to the desert by excreting concentrated urine. Lack of sweat glands, possession of salt secreting glands and large ears to radiate heat are morphological adaptations for checking loss of water and keeping the body cool. Sahara desert in Africa is the largest in the world. Other deserts are found in Australia, North America, Gobi desert in Mongolia, Chile etc. In Pakistan the deserts found are of varied types.

Tundra Ecosystem

Tundra is a Finish word meaning open forestless country and is used to

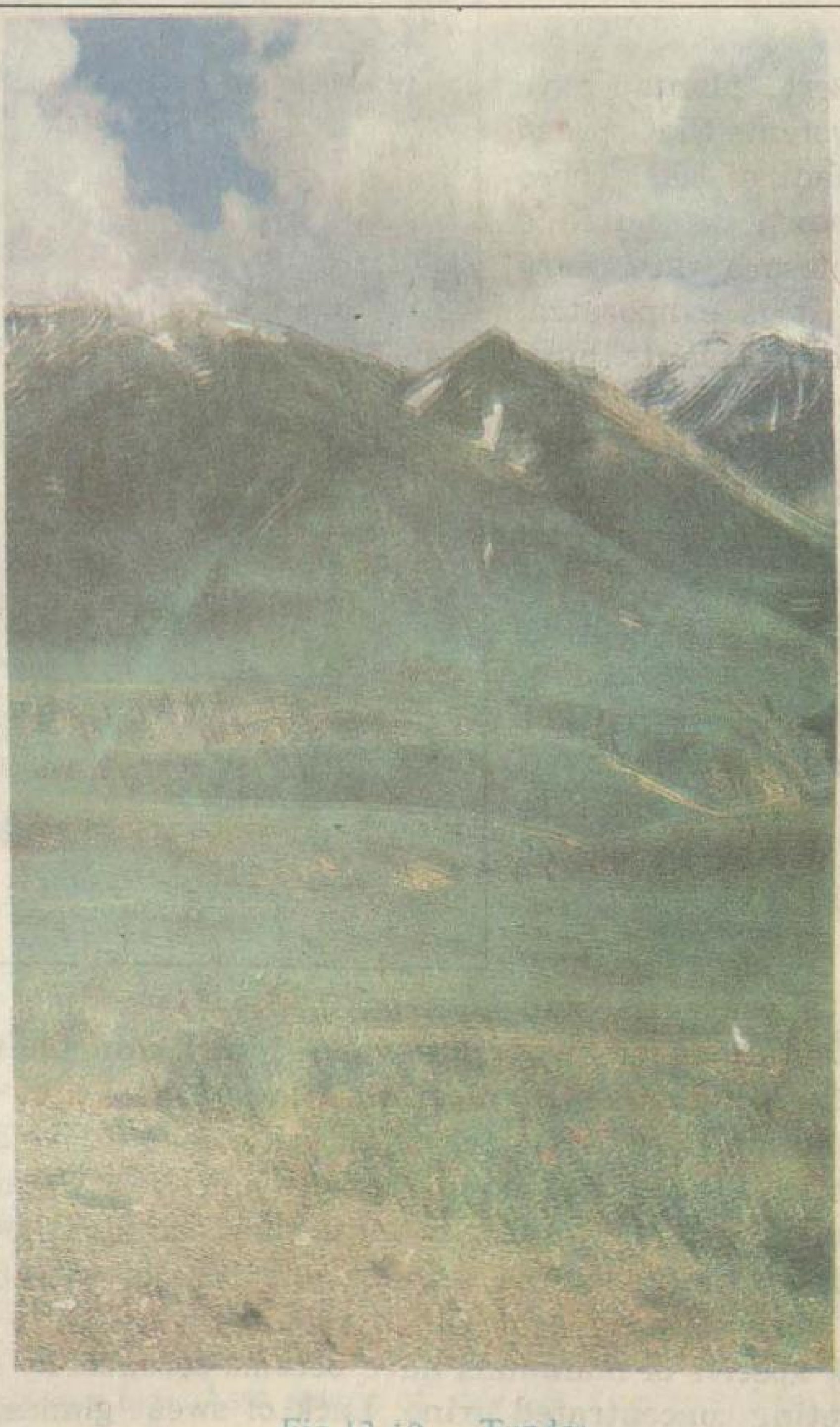


Fig 13.19. Tundra.

describe all types of vegetation in treeless high latitudes between Taiga and polar ice caps, and at high altitude across the mountain above timberline such as Karakoram HinduKush mountain.

The tundra of the high latitudes some times called as arctic tundra, stretches across northern North America, northern Europe and Siberia. Tundra of the high altitude is sometimes called the alpine tundra. In both the tundras temperatures are low with strong sweeping winds and water is available only during a short growing season. However, the most important feature of the tundra is permafrost, a subsoil layer which remians permanently frozen. The permanently frozen subsoil layer forms an impenetrable layer restricting root growth. The uppermost 10 to 20 cm thick layer of soil also remains frozen except during the short summer season when it thaws.

The producers of the tundra are dominated by herbaceous plants such as grasses, sedges, rushes and heaths. Below this is well developed layer of mosses and lichens and other small perennial flowering plants. The permafrost, harsh winters and low primary productivity put strong limits on permanent fauna. Large mammals of the arctic tundra such as caribou, reindeer and musk ox are migratory, because there is not enough vegetation produced in any one local area to support them. A few birds stay in the tundra for the whole year. Those which do so such as ptarmigans and grouse, have large feet which act as snow shoes. Predators include arctic foxes, wolves and polar bear. During summer months, many birds like ducks and geese use the temporary pools and ponds as their breeding ground.

Ultraviolet radiations, in the alpine tundra, is intense. The rosette forming plant, characteristic of alpine tundra producers are thought to be the result of these radiations.

QUESTIONS

1. What is meant by Abiotic and Biotic factors of the environment? How do they influence each other in an ecosystem?
2. Discuss variations of temperature that occur in different ecological habitats.
3. Describe role of water in the ecosystem. What is water cycle?

4. Discuss one of the following abiotic factors:
   a) Topography
   b) Gravity
   c) Fire.
5. "No new life could be produced without decomposers" Discuss.
6. What ecological zones are found in standing and running water bodies? Give a brief description of them.
7. Give a brief description of the different life zones into which an ocean is divided.
8. What problems are faced by land organisms and how do they solve them?
9. Give an accounts of any one of the following ecosystems:
   a) Grass land
   b) Desert
   c) Tundra
   d) Tropical rain forest.

INTERACTIONS IN ECOSYSTEMS

14

We know, by now, that organisms in an ecosystem are interacting with one another, as well as with the non-living environment. Plants and animals associate temporarily or permanently with organisms belonging to different species. The association results in developing intricate interactions amongst the individuals. Interaction between organisms may be harmful (negative), beneficial (positive) to one or both of the interacting species or may be harmful to one and beneficial to the other species. Some of such positive and negative interactions and related concepts are described in this chapter.

Predation

A **predator** is an animal which captures and readily kills live animals for its food. The animal killed and eaten is the prey. **Predator-prey relationship** has an important bearing on the distribution and abundance of organisms. The predator is commonly believed to regulate the population density of its prey. Actually the relation is somewhat balanced. If a prey population increases, it will support more predation as a result the population of the latter also increases. If the prey is killed in large numbers, then its population size will be reduced. As a result the density of the predators will then be slightly out of place with regard to the number of prey. Such fluctuations may occur in wild populations. The predator-prey interaction, therefore, helps in maintaining the ecosystem stable. A species in the area without its natural predator leads to disastrous results. The introduction of rabbits into Australia without the predator multiplied to enormous numbers and proved a menace to the farmers.

Parasitism

Parasitism is an association between organisms of different species in which one individual is benefited (parasite) and the other though harmed (host) is not killed until the parasite has completed its reproductive cycle. Parasitism is mainly a food co-action in which the parasite derives shelter and protection from the host. Parasite may be plants or animals. They may be **ectoparasites** i.e., human louce on mosquitoes or **endoparasites** i.e., round worm and plasmodium. Ectoparasites live on the surface of the host whereas endoparasites live within the host. Parasites may be specific and restricted to one host or they may require more than one hosts.

In contrast to a predator, a typical parasite that lives on the tissues or food of its host does not kill the host outright but continue to feed on the living host. As the survival of the parasite depends upon the life of the host, successful parasites, therefore, avoid heavy infestation of the host. Therefore, they have a rapid rate of reproduction. Many parasites complete their life cycle in two different hosts. They exhibit an astounding diversity in ways and means to exploit their hosts. They thus may be **viral parasites, microbial parasites, phytoparasite or zooparasite.**

Symbiosis

Symbiosis is an association between organisms belonging to different species which live together for mutual benefit or one partner gets benefit and the other is neither benefited nor harmed. Thus symbiotic associations are of two different types, namely mutualism and commensalism.

1. Mutualism

Symbiotic association in which both the partners get benefit and neither can survive without the other is called **mutualism.** In certain cases of mutualism the two partners remain continuously associated. A striking example is that of a ruminant animal such as a cow and the bacteria that live in its gut. The cow cannot digest cellulose (the main component of its food) whereas the bacteria can do so, because they produce a cellulose splitting enzyme called **cellulase.** Another example is that of termites and flagellate protozoa. The termite eat wood but cannot digest cellulose, but the flagellates in the termite's gut can. In this way food is available for both. Some other important examples are mycorrhiza, lichens, root nodules and nitrogen fixing bacteria.

Mycorrhiza is a symbiotic association between a fungus and roots of higher plants. The fungus may form a sheath which covers the lateral roots of forest trees or the fungus may be present inside the roots of a wide range of crop plants and trees. In most of the cases, the fungus, for its food, depends on the photosynthate of the tree. However, in some cases, the fungus is able to digest lignin and cellulose in the soil. The benefit derived by the mycorrhizal plant is not properly understood. However, it is known that plants with mycorrhizal association show better growth than those without the fungal partner. A lichen is the association between a fungus and an alga. Lichens are found as leaf-like or crust growths on stones and tree barks. The association of algae and fungus in the lichens are of mutual benefit to both alga and the fungus. Fungus gets the food from algae and in return provides protection to algae from intense sunlight, desiccation and supply it absorbed mineral nutrients.

2. Commensalism

This is symbiotic association in which one partner gains benefit without benefiting or harming the other. In some cases the two partners remain permanently associated with one another. For example, barnacles attached to the backs of whales and turtles, get a free ride to better feeding places. Certain crabs live in the mantle cavities of sea mussels for protection. Similarly crabs that live in the tubes of annelid worms and lichens growing on trunk of woody trees are other examples of this type.

Grazing

Cattle, sheep, horses and rabbits are examples of the grazers. Their natural habitat is pasture land where they feed on grasses and herbs growing there. Grazing affects some plant species more than others. Grasses are more tolerant of grazing, because they have the ability to regrow rapidly after being nibbled. The degree of grazing is very important in determining its overall effects on the ecosystem. Moderate grazing, helps to maintain grasslands by destroying the competitors like tree seedlings and preventing their encroachment.

The effect of trampling by grazing animals, in making the soil compact is also important. Too many animals when trampling for too long a time make the soil "sod bound" which is hampered by poor aeration and which in turn leads to poor growth. If overgrazing and trampling continues, the weeds, in turn can be reduced in coverage and the soil depending on location would be exposed to erosion. The final result of over-grazing is a virtual barren mud fields or badly eroded rocky slopes i.e., foothills of the Suleman range in Pakistan.

CYCLES IN AN ECOSYSTEM

Dead bodies of plants and heterotrophic organisms are decomposed by micro-organisms and substance called nutrients are released in the environment. These nutrients are used by plants in their growth which in turn form food for the heterotrophic organisms. These back and forth movements of chemical elements between organisms and environment along characteristic circular paths are known as **biogeochemical cycles.** Carbon-Hydrogen-Oxygen cycle and Nitrogen cycle are being described in detail.

Carbon-hydrogen-Oxygen Cycle

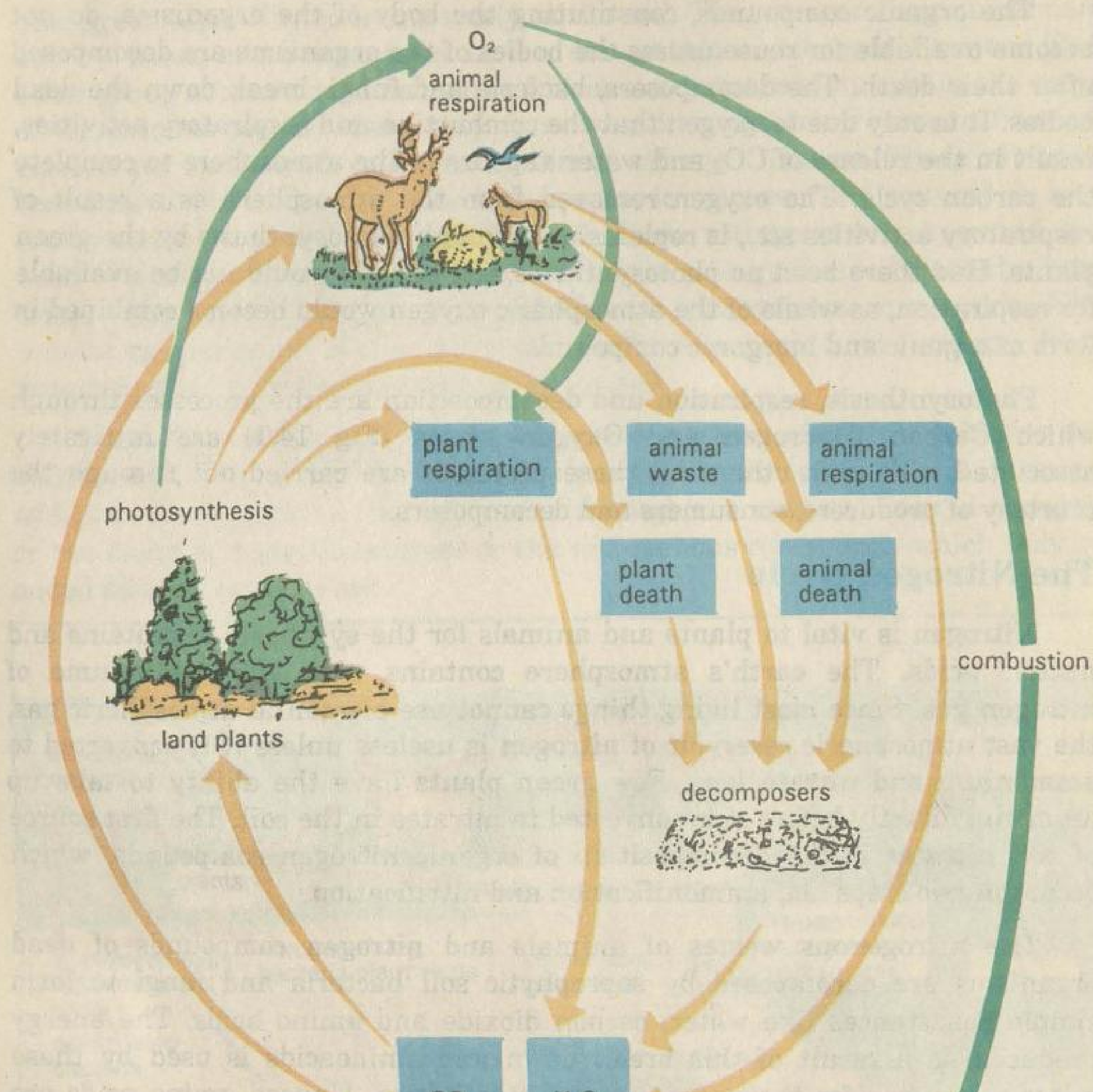
We know that all the organic compounds contain carbon. This carbon is present in two forms i.e., as carbon dioxide in the air and mostly as bicarbonate and carbonate in water and in the rocks. The carbon available in form of fossil fuels etc, is of no use to organisms, unless it is burnt to produce carbon dioxide. All green plants both terrestrial and aquatic use carbon dioxide for photosynthesis. Not all the organisms are capable of utilizing carbon dioxide directly, but only the green plants can. Animals and non-green plants use carbohydrates, proteins and fats etc. as a source of carbon and oxygen.

Green plants take up CO_2 and H_2O from the environment and convert them into glucose in the presence of solar energy. The generalized equation for this process of photosynthesis is:

$$6CO_2 + 6H_2O \xrightarrow[\text{energy}]{\text{solar}} C_6H_{12}O_6 + 6O_2$$

The plants use this food (glucose) for their own growth and development and when the plants are consumed by the heterotrophic organisms, a part of the material is transferred to their bodies. The carbon and hydrogen, in the bodies of these animals is released once again into the environment in two ways: respiration and decomposition. Both of these processes are essentially energy releasing. This energy is utilized by the organisms in performing their life functions. In respiration the glucose is oxidized to release free CO_2 and H_2O alongwith energy. It is represented by the following equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$


O₂
animal respiration
photosynthesis
land plants
plant respiration
animal waste
animal respiration
plant death
animal death
combustion
decomposers
CO₂
H₂O

water is lost by drainage to ocean. CO_2 is lost by washing away of soluble carbonates into oceans.

CO_2 is added to the cycle by combustion of natural fuels and weathering of carbonate rocks water is added by rainfall

Fig. 14.1. The Carbon-Hydrogen-Oxygen cycle on land.

The organic compounds, constituting the body of the organisms, do not become available for reuse unless the bodies of the organisms are decomposed after their death. The decomposers, bacteria and fungi, break down the dead bodies. It is only due to oxygen that the combustion and respiratory activities, result in the release of CO_2 and water vapours to the atmosphere to complete the carbon cycle. The oxygen removed from the atmosphere as a result of respiratory activities etc., is replenished through photosynthesis by the green plants. Had there been no photosynthesis, the oxygen would not be available for respiration, as whole of the atmospheric oxygen would become combined in form of organic and inorganic compounds.

Photosynthesis, respiration and decomposition are the processes through which Carbon, Hydrogen and Oxygen cycles (Fig 14.1) are intricately associated with each other. All these processes are carried out through the courtesy of producers, consumers and decomposers.

The Nitrogen Cycle

Nitrogen is vital to plants and animals for the synthesis of proteins and nucleic acids. The earth's atmosphere contains over 78% by volume of nitrogen gas. Since most living things cannot use elemental atmospheric gas, the vast atmospheric reservoir of nitrogen is useless unless it is converted to ammonium and nitrate ions. Few green plants have the ability to take up ammonia directly before it is converted to nitrates in the soil. The first source of soil nitrates is the decomposition of organic nitrogen compounds, which occurs in two steps i.e., ammonification and nitrification.

The nitrogenous wastes of animals and nitrogen compounds of dead organisms are decomposed by saprophytic soil bacteria and fungi to form simple susbstances like water, carbon dioxide and amino acids. The energy produced as a result of this break down and aminoacids is used by these micro-organisms for their own metabolic activities. Unused amino acids are converted into ammonia or ammonium ions. The process is known as **ammonification.** Some ammonia escapes into the soil atmosphere but much of it and ammonium ions are converted into nitrates by nitrifying bacteria, in soil. Nitrification is accomplished by two groups of nitrifying bacteria. The first group like **Nitrosomonas** converts ammonia to nitrites and the second like **Nitrobacter** converts nitrites into nitrates. Nitrification takes place only in well aerated soils because the bacteria responsible for it are aerobic.

The second source of soil nitrates is the nitrogen fixation which is brought about by certain micro-organisms. These are of two types. One group of such organism are bacteria Azotobacter and Clostridium; and the other a blue green alga, Nostoc living freely in the soil. The nitrogen fixation carried out by these micro-organisms is the non-symbiotic nitrogen fixation. The other group of micro-organisms like Rhizobium live symbiotically in the roots of leguminous plants where they form wart like nodules. Nitrogen fixation carried out by them is called as symbiotic nitrogen fixation. These nitrogen fixers have the ability to absorb atmospheric nitrogen and convert it into nitrogenous compounds of their bodies. These nitrogenous compounds are used to manufacture proteins with the help of energy derived from the host tissue. The host in return is supplied with nitrogenous compounds. Soil inhabiting nitrogen fixing bacteria derive the necessary energy from decomposed organic matter (humus) in the soil.

When these organisms die, the nitrogenous compounds of their bodies are decomposed and converted into soil nitrates. In the case of root nodules, additions of nitrogen to the soil occurs through the death of the old nodules, or the death of roots themselves or the nitrogenous compounds which may be added directly into the soil.

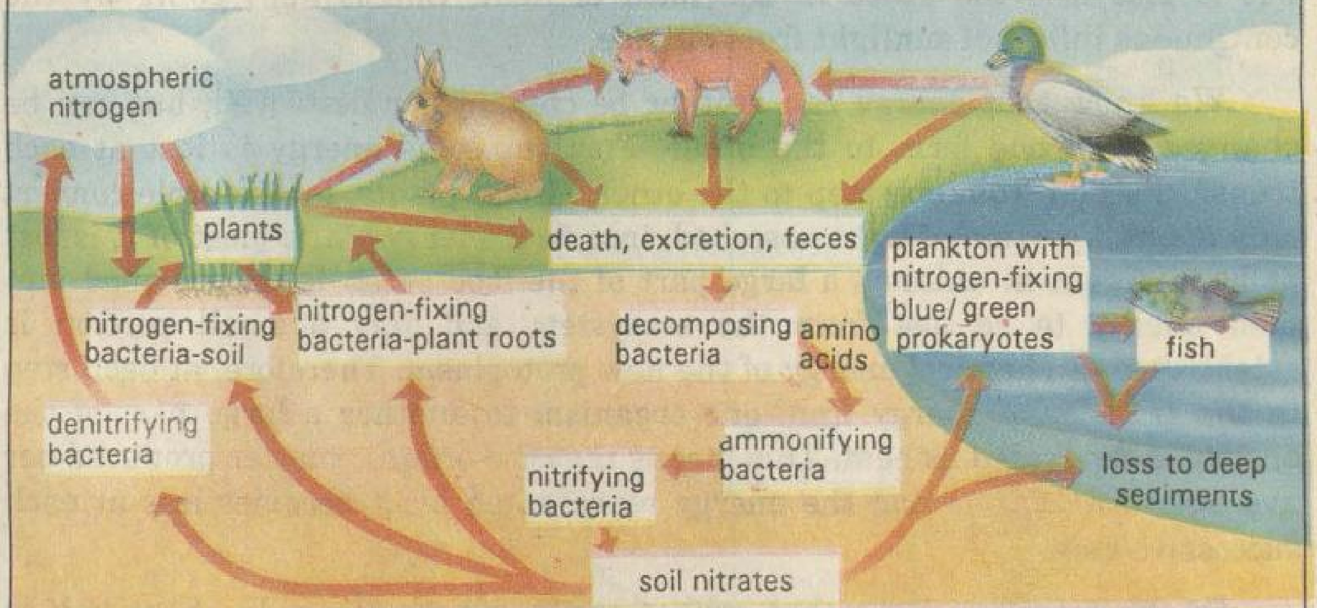

atmospheric nitrogen
plants
death, excretion, feces
plankton with nitrogen-fixing blue/green prokaryotes
fish
nitrogen-fixing bacteria-soil
nitrogen-fixing bacteria-plant roots
decomposing bacteria
amino acids
denitrifying bacteria
ammonifying bacteria
nitrifying bacteria
loss to deep sediments
soil nitrates

Fig. 14.2. The nitrogen cycle

The third source of soil nitrates are the thunderstorms. During thunderstorm nitrogen combine with oxygen to form various oxides of nitrogen. When dissolved in water these oxides form nitrous and nitric acids. In the soil these acids combine with mineral salts to form nitrates eventually (Fig 14.2).

Loss of soil nitrates may occur by the activities of denitrifying bacteria, such as Pseudomonas which reduce nitrates in the soil to gaseous nitrogen. The nitrogen so formed escapes into the air. Soil nitrates are also lost when top soil is carried off by soil erosion or when ground cover is burnt by fire. In cultivated land, most of the nitrogen previously in the soil is removed in the crop at the time of harvesting. Thus soils, under cultivation, show a steady decline of nitrogen content and need to be treated with nitrogen fertilizers.

ENERGY AND ITS FLOW THROUGH AN ECOSYSTEM

In contrast to cycling of essential elements and minerals, energy flows only once through the ecosystem and in one direction only. In the end it is lost from the ecosystem and the biosphere. The energy source for all ecosystems is the sun. The green plants synthesize food with this energy. The energy trapped in the form of food is then passed on to the herbivores and then to the carnivores. From the top carnivores energy is not available again but is lost into the space in the form of heat. Life is kept going by the continuous inflow of sunlight from outside.

We know that energy can neither be created nor destroyed, but can be changed from one form to the other. Further, some energy is lost at each transformation from one step to the other. Green plants, for example convert only a small portion of light absorbed, into food energy while most of it is lost as heat. Again in animals a large part of the food eaten is transformed into heat energy to be lost from the ecosystem and only a small portion is established as chemical energy of the new protoplasm. Therefore, at each step in the transfer of energy from one organism to another a large part of the energy is dissipated as heat. This means that the organic matter produced per average unit of time and the energy represented by it becomes less at each successive step.

Of the total sun light that strikes the green plants, only about half is absorbed by the photosynthetic machinery, the rest is reflected or transmitted through the leaf surface and some dispersed in the form of heat energy. Roughly about 25% of what is absorbed is used in photosynthesis and ends up in chemical energy of food. This total photosynthate is the gross production. A substantial amount of the gross production is used by the plants themselves for their life processes. Whatever is left of this gross production is the net production which comes up to about 10% per cent of light absorbed or 40% of gross production. Net plant production, therefore, is the total carbohydrate formed minus the respiration and it is this energy which is available to the heterotrophs.

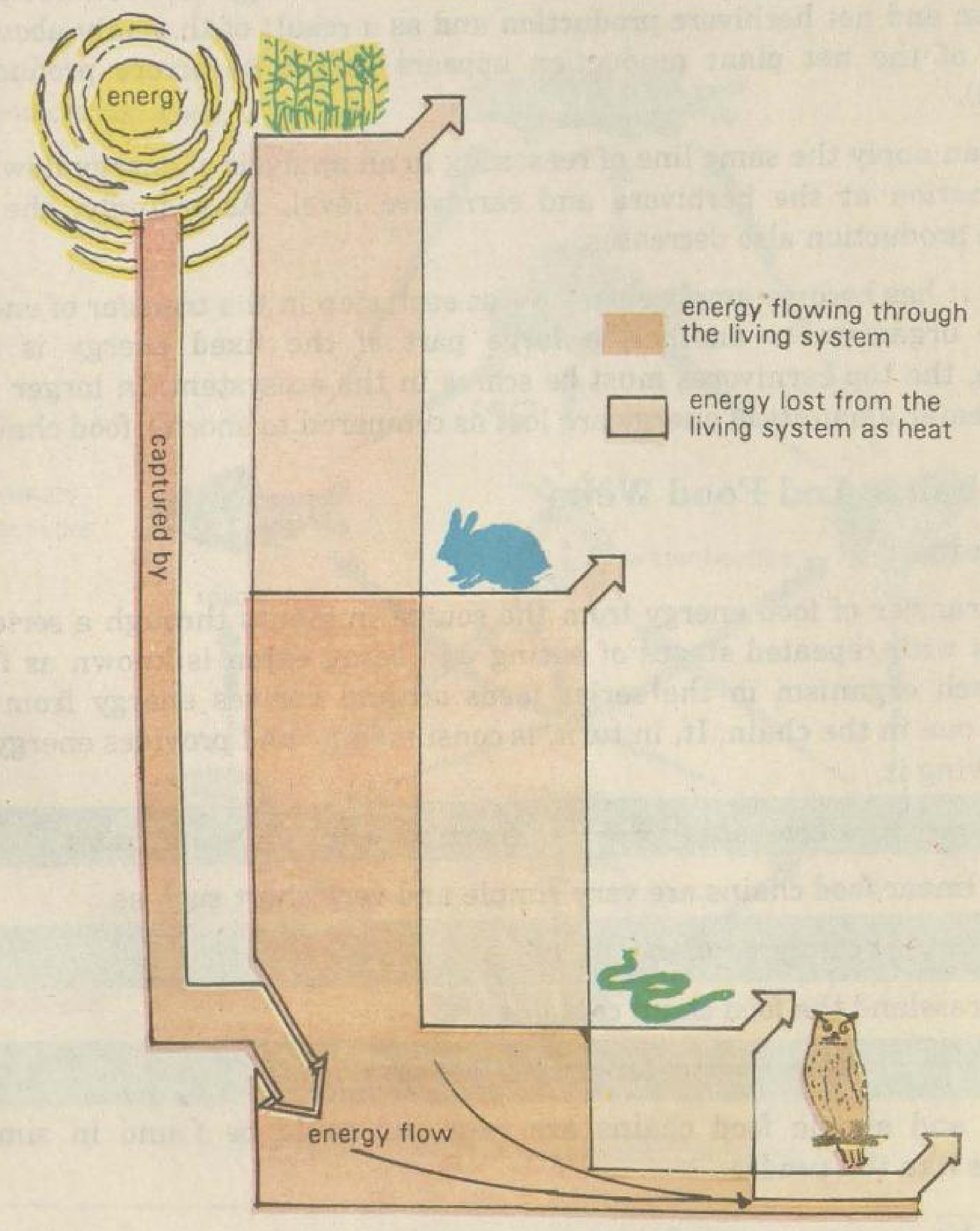

energy
captured by
energy flowing through the living system
energy lost from the living system as heat
energy flow

Fig. 14.3. Energy flow in ecosystem

Part of the biomass (plant material) formed in the ecosystem is consumed by herbivores, the rest either dies or is not used by herbivores. A portion of plants consumed by herbivores is not assimilated. The total plant material assimilated by the herbivores will be gross production at the herbivore level. A substantial amount of gross production is used by the herbivore respiration and what is left and appears as the herbivore material is the net production at the herbivore level. Thus there are four leaks of energy between net plant production and net herbivore production and as a result of this only about 10 per cent of the net plant production appears as net herbivore production (Fig. 14.3).

We can apply the same line of reasoning to an analysis of energy flow and transformation at the herbivore and carnivore level. Accordingly, the net carnivore production also decreases.

Thus it has become amply clear how at each step in the transfer of energy from one organism to another, a large part of the fixed energy is lost. Therefore, the top carnivores must be scarce in the ecosystem. In larger food chains greater amounts of energy are lost as compared to shorter food chains.

Food Chains And Food Webs

Food Chains

The transfer of food energy from the source in plants through a series of organisms with repeated stages of eating and being eaten is known as **food chain.** Each organism in the series feeds on and derives energy from the preceding one in the chain. It, in turn, is consumed by and provides energy for that following it.

Producers ⟶ Herbivores ⟶ Consumers ⟶ Decomposers

Some linear food chains are very simple and very short such as

grass ⟶ cow ⟶ man.

In a grassland the food chain could be

grass ⟶ mole ⟶ fox ⟶ bacteria.

Short and simple food chains are rare and could be found in simple ecosystems like the tundra.

Food Webs

Although simple linear food chains can be found in simple ecosystem, feeding relationships amongst organisms in a community are frequently more complicated. In complex ecosystems there are many alternate sources of food for the herbivores and the herbivores in turn may be preyed upon by several different predators. Consequently the linear food chains interconnect to form food webs. A simple fresh water food web is shown in Fig 14.4.

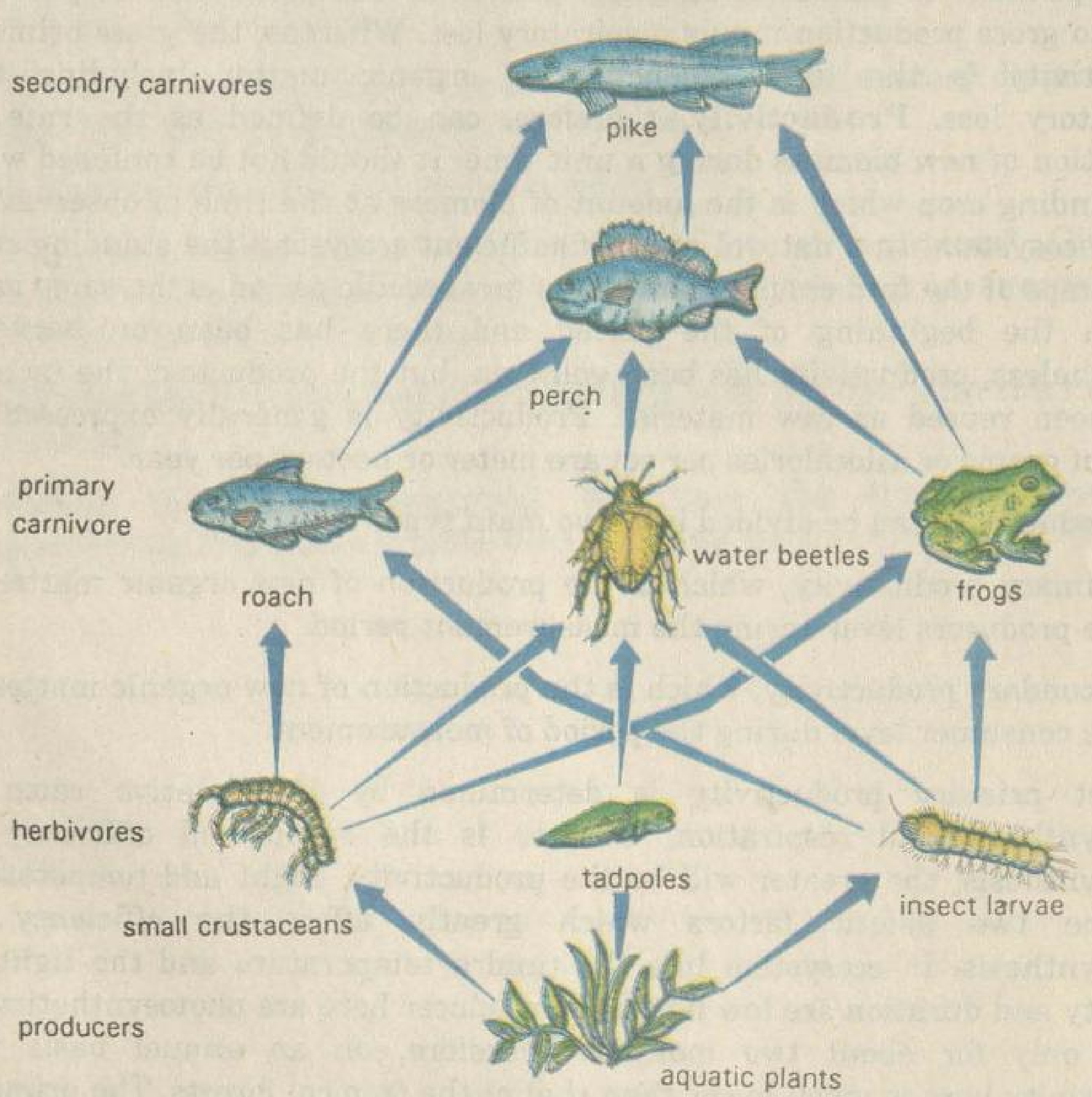

secondry carnivores
pike
perch
primary carnivore
roach
water beetles
frogs
herbivores
small crustaceans
tadpoles
insect larvae
producers
aquatic plants

Fig. 14.4. A simple fresh water food web.

The alternative path ways in a food web help to maintain the stability of the ecosystem. The greater the number of alternative pathways in a food web, greater will be the stability of community of animals living in a fresh water pond.

PRODUCTIVITY OF AN ECOSYSTEM

We have seen that the radiant energy of sun fixed as chemical energy of food by producers is the gross production. All of this does not appear as photosynthate or plant growth because much of the photosynthate is used in the respiration of plants. Thus, plant growth or net production of plant is equal to gross production minus respiratory loss. Whereas, the gross primary productivity is the total production of organic matter including the respiratory loss. **Productivity,** therefore, can be defined as the rate of production of new biomass during a unit time. It should not be confused with the standing crop which is the amount of biomass at the time of observation in the ecosystem. In a natural and self sufficient ecosystem the standing crop at all steps of the food chain at the end of any specific period is the same as it was in the beginning of the period and there has been no harvest. Nevertheless, productivity has been going on, but the products of the factory have been reused as raw material. Productivity is generally expressed in terms of grams or kilocalories per square meter or hectare per year.

Productivity can be divided into two main type:

(a). Primary productivity, which is the production of new organic matter at the producers level during the measurement period.

(b). Secondary productivity, which is the production of new organic matter at the consumer level during the period of measurement.

Net primary productivity is determined by the relative rates of photosynthesis and respiration. Greater is the speed and efficiency of photosynthesis, the greater will be the productivity. Light and temperature are the two abiotic factors which greatly affect the efficiency of photosynthesis. In ecosystem like the tundra temperature and the light in quantity and duration are low hence the producer here are photosynthetically active only for about two months. Therefore, on an annual basis the productivity here is much lower than that of the tropical forests. The primary productivity in its own turn determines the secondary productivity. It means that greater is the productivity greater will be the biomass supported by the ecosystem.

QUESTIONS

1. "Predation is an interaction which can be beneficial for both the prey and the predator". Give arguments for and against the statement. How do predation and parasitism differ from each other?

2. What is mutualism? Explain with the help of two examples, one from animals and one from plants.
3. Differentiate commensalism from mutualism by giving at least two examples from each.
4. Write an essay on grazing.
5. Explain the term biogeochemical cycle. Give an explanatory diagram to show Nitrogen cycle. No description is needed.
6. Describe Carbon-Hydrogen-Oxygen cycle.
7. How does energy flow differ from cycling of nutrients? Give a comprehensive diagram showing all the steps involved in energy flow through various trophic levels.
8. Differentiate between food chain and food web. Explain with the help of diagrams.
9. Explain the term productivity. What are the different types of productivity? How does it differ from standing crop?

MAN AND HIS ENVIRONMENT

15

Environment is a treasure of all types of resources (i.e., land, water, air, minerals and forests etc.) essential to sustain life on earth. Humans depend on the environment, both directly and indirectly for food, shelter, clothing, fuel and other materials essential for present-day-life.

Early man found land amazingly rich in these environmental resources and exploited them eagerly and often wastefully. His interest was to cut more and more forests, plough more land, mine minerals and kill animals. These resources seemed unlimited and few people thought that they could be exhausted. Scientists soon realized that even the most plentiful resources can become exhausted or can be so damaged that they become useless. Future of mankind depends on how wisely we use the earth's resources now. Earth is a self-contained unit and its resources are limited.

ENVIRONMENTAL QUALITY

Humans can change the environment by their activities. People have lived on this planet earth for hundreds of thousands of years. Only in the last few hundred years man developed industries capable of providing more food, better clothing, shelter and transportation to large number of people. In order to provide these necessities of life to an ever-increasing human population, we are using the environmental resources of earth at an increasing rate and the waste materials resulting from our activities are increasing, thus creating environmental pollution problems.

So long human population was relatively small in relation to the total environment available, his activities produced little more than local effects. The water, the land and the air seemed able to absorb the wastes and the abuse of his activities. The wastes, man dumped into the river waters were diluted, degraded and purified before the same waters were used downstream.

The burning of fossil fuels created local air pollution problems. As cities developed and expanded because of increase in population, more sewage entered the rivers and more gases were poured into the atmosphere and the conditions gradually became worse.

During the last two decades, local problems of environmental pollution have become global problems. New industrial products, toxic chemicals and non-degradable solid wastes of the modern technologically advanced society have polluted air, land and water. Plants, animals and even ecosystems are unable to adapt to these changes. In brief, the environmental problems of resource depletion and the environmental quality degradation are the direct result of advances in technology and human population growth.

RENEWABLE AND NON-RENEWABLE RESOURCES

Environmental resources are elements of nature which serve as primary sources for the existence of humans. These are classified as renewable and non-renewable resources. Air, water, food, land, forests, fish and wild-life are renewable resources. These are considered renewable as they are never depleted. Natural cycles are constantly replacing these materials, while they are being utilized by living organisms. For example, animals take oxygen from air during respiration and return carbon dioxide. Plants, on the other hand, take in carbon dioxide and return more oxygen than they consume during respiration. This interaction of plants and animals maintain balance of oxygen and carbon dioxide in the atmosphere. Similarly, the natural cycle of evaporation and precipitation (rain fall) maintains a continuous supply of fresh water on the earth.

Non-renewable resources include various metals, non-metallic minerals and fossil fuels (coal, oil and natural gas). These resources are exhaustable and cannot be reused or replaced if depleted or destroyed. They will be finished for ever. Modern man is using these resources extensively and they may be depleted very soon. It is high time that man should realize the consequences of depletion of these resources on his future and survival of mankind on planet earth. Some of these renewable resources and their degradation is discussed below:

(I) Air

Several kilometre thick blanket of atmosphere surrounds the planet earth. Importance of air in which we breathe for oxygen and survive, can hardly be over-emphasized as a natural resource. Air consists mainly of oxygen (about 20%); carbon dioxide (0.03%); nitrogen (about 79%); minute traces of inert gases (helium, neon, krypton, argon,xenon) and water vapours in varying amounts depending upon weather conditions. Except for the inert gases, all these components of air serve as raw material for living organisms and each circulates in a natural cycle (as discussed in the previous chapter). All these gases are also soluble in natural waters, hence aquatic organisms, like terrestrial ones, can also utilize these aerial raw materials.

During most of human history air was clean. During industrial revolution of eighteenth century the use of coal to run factories increased greatly. Thick clouds of smoke containing soot and other particles pouring out of factory chimneys (Fig. 15.1) caused health problems, such as respiratory diseases and irritation of eyes of the people living in factory areas. Particulate air pollutants also affect clothes, houses and buildings.

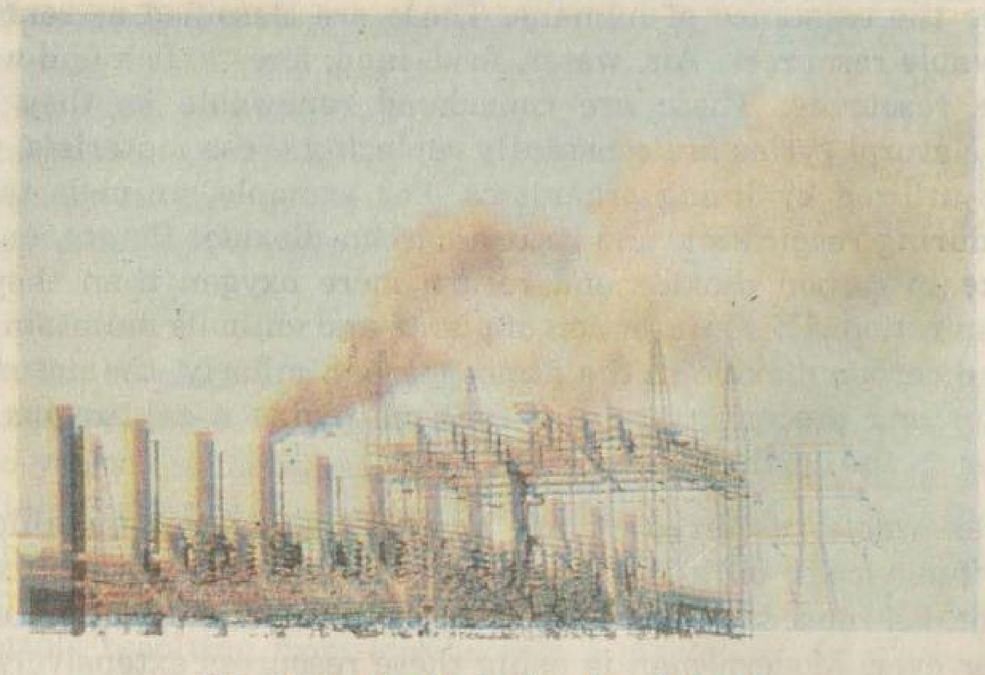


Fig. 15.1. Smokestacks of an industry

In the recent past, internal combustion engine of a variety of automobiles (aeroplanes, buses, vans, trucks, cars, autorickshaw and scooters) have become greatest sources of air pollution (Fig 15.2). It is a matter of common observation that more people with more automobiles have become crowded in less space in big industrial cities of the world. Thus, the air of the meteropolitan areas has become greatly polluted with gases produced from ever increasing number of automobiles.

Fig. 15.2. (a)

Exhaust from an aeroplane adding to air pollution

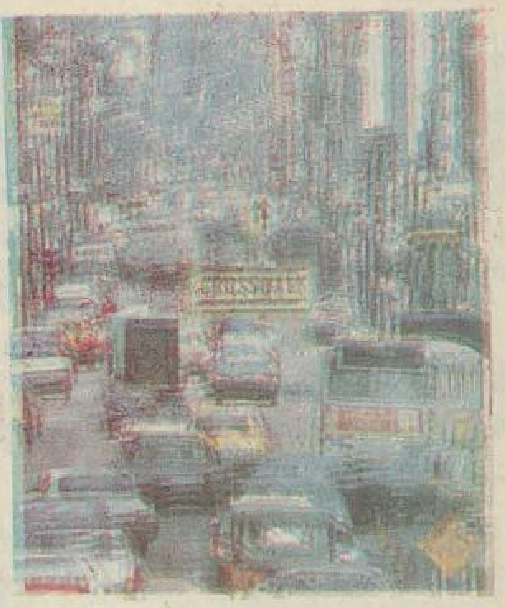


Fig. 15.2. (b)

Pollution due to cars, trucks autorickshaws and scooters.

Polluted air contains certain gases; like carbon monoxide, hydrocarbons and oxides of nitrogen and sulfur. Carbon monoxide is a poisonous gas and 1% of this gas in the air can kill a person in five minutes. It is produced when fossil fuels are burnt in the presence of limited quantities of oxygen in factories, furnaces and automobiles.

(a) Green house Effect: Apart from local effects of air pollution, green house effect and acid rains are global effects of air pollution. Enormous quantities of carbon dioxide are injected into the atmosphere from fossil fuel burning, furnaces and breathing of animals. About half of the carbon dioxide in the atmosphere is utilized by plant life or absorbed by water of oceans and the rest continues to accumulate in the lowermost layer of the atmosphere forming a thick dense layer. In dense concentrations carbon dioxide acts as a serious pollutant. Under conditions of normal carbon dioxide concentration in the atmosphere, sun rays strike the earth in the form of visible light of short wavelengths and heat it up. The heated earth re-radiates this absorbed energy back into the space in the form of the radiations of long wavelengths thus maintaining temperature balance of earth's atmosphere. Thick layer of carbon dioxide allows the sun rays to reach the earth and get converted into heat, but prevents the re-radiation of this absorbed heat energy back into the space. Much of this energy gets absorbed in the carbon dioxide and moisture in the atmosphere and adds to the heat that has already been there. Hence there is more heating of earth's atmosphere. This phenomenon is known as **greenhouse effect**. Thick layer of carbon dioxide thus acts like the glass of a greenhouse, which allow the entry of incoming solar radiation, but prevents the emission of the outgoing heat waves. Thus accumulation of carbon dioxide on global scale tends to warm the air in the lower levels of the atmosphere.

Increased heating of earth due to greenhouse effect could cause melting of ice-caps in the polar regions, receding of glaciers, early melting of snows in mountains and more floods during monsoons. The sea levels will rise and coastal towns can sink.

(b) Acid Rains: Sulfur dioxide and nitrogen dioxide emitted in the air, during the burning of fossil fuels, are higly soluble in water vapour present in the atmosphere and form acids like sulfuric acids, sulphurous acids, nitric acid and nitrous acid. These then return to the earth with rain water and is known as **acid rain**. Acid rain causes a number of adverse effects. It tends to increase the soil acidity, destroys forests and crops and threatens human life as well as aquatic life in lakes. Sulfuric acid mist when inhaled can damage lungs. It also has corrosive effect on building stones and may damage them with the passage of time. In fact it is known as **stone cancer.**

Air always seemed so vast in quantity and so readily available free of cost. Nevertheless, air over major industrial cities throughout the world has become over-burdened with its share of gases produced by automobiles. The death rate due to automobile pollution is increasing rapidly in the metropolitan areas. In Pakistan, air pollution has increased tremendously in commercial areas of major cities like Karachi, Lahore, Faisalabad, Multan and Sialkot.

(II) Water

Water covers some 70% of earth's surface and is also a component of soil and air. It is also a major constituent of living organisms (animals and plants) comprising 70-90% of their body weight. Calculations by various scientists estimate that 97% of total water of planet earth is in oceans; 2% in the form of frozen ice-caps and glaciers and only 1% as available freshwater in lakes, streams and rivers (Fig 15.3).

Fig . 15.3. (a) Ice-caped mountains.

Fig. 15.3. (b) Glaciers in northern region in Pakistan

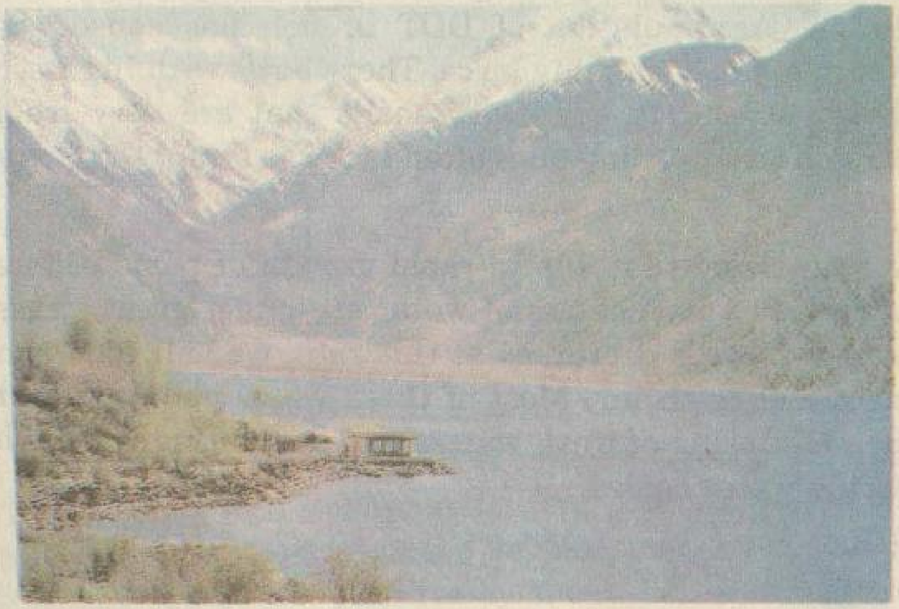


Fig. 15.3. (c) Fresh water: glaciers fed river in northern area in Pakistan

Water is used by humans for domestic, irrigation and industrial purposes. It is also used for commercial transportation of goods, all over the world, by merchant navy. Domestic uses include drinking, bathing, washing of clothes etc. Total domestic consumption of water, however, is only 10% as compared to 90% used in irrigation and industry. Another traditional and major use of water is transportation of wastes including industrial wastes of cities.

In the past, rivers were used as source of pure water and a means of removing wastes (consequently all the major civilizations of the world such as Indus valley civilization and Nile valley civilization developed along the banks of the rivers). Wastes emitted into the rivers were consumed by micro-organisms and a few kilometers, downstream the water was pure again. With the increase in population and industry so much of sewerage and industrial wastes were produced and dumped into the rivers, that the micro-organisms could not decompose and recycle them before the water reached the next city. Industries also consume vast quantities of water and much of it is polluted with chemicals when returned to river.

These chemical wastes are often extremely toxic. They either kill the micro-organisms that purify water or inhibit their growth. Chemical wastes not only pollute and degrade the river water quality but are harmful to other aquatic organisms as well. DDT, mercury compounds and other pesticides may enter the aquatic food chain and accumulate in the tissues of organisms. Fish population of many lakes and rivers has decreased due to industrial waste pollution. Accumulation of DDT in fish has caused decline in the population of many fish-catching birds. These birds with high accumulation of DDT, in their tissues, lay eggs with shells that are very fragile and often break. In certain cases, young ones often lack the strength to emerge from the egg.

It may be realized that due to rapid growth of population and industry, the natural cycles of purification of water are under great stress. If pollution of fresh water resources continues at this rate, we will soon run out of fresh water as we are of clean air. Most of these water pollution problems can be overcome by monitoring of fresh waters and preventing the discharge of toxic materials in the water bodies.

(III) Land

Land is an important natural resource and is basic in food production. The growing crops continuously remove nutrients from the soil. Generally these nutrients are returned to the soil by decomposition of dead, decaying remains of plants and animals. Due to repeated crop production and its consumption by human population as food, some nutrients are not returned to the soil and as a result soil fertility is reduced. This is called **soil depletion.** Chemical fertilizers are used to replace nutrients in depleted soils. Crop rotation can also help soil to regain its lost nutrients. In crop rotation some leguminous plants are altered with major crops such as wheat, rice or corn. The leguminous plants return nitrogen to the soil due to the activity of nitrogen fixing bacteria present in the nodules of their roots.

Land may be abused in many ways such as erosion, poor agricultural practices and extensive grazing. Erosion is a natural process in which surface soil is removed by the action of water or wind (Fig. 15.4). In agricultural lands growth of crops limits the amount of erosion to a great extent. However, careless farming methods such as extensive ploughing of lands especially in arid regions of the world expose the surface soil to the erosive influence of wind and water. Grazing of pastures by sheep, cattle and horses may destroy the plant cover and expose the soil. Thus accelerated erosion due to human activity may destroy soil structure and convert this renewable resource into a non-renewable one.

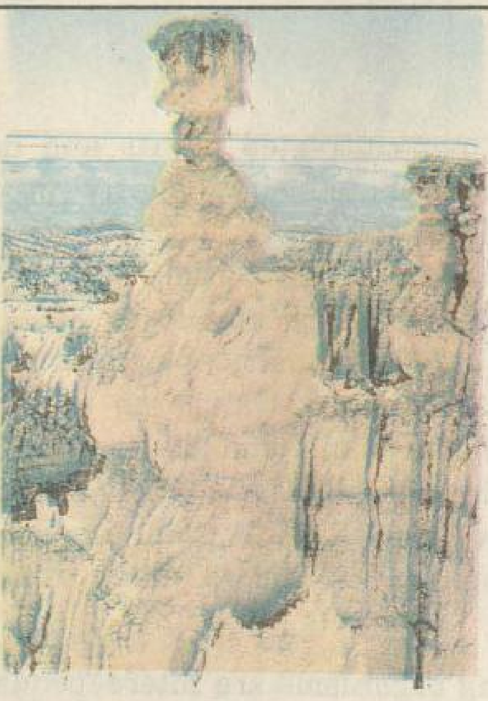


Fig. 15.4. Erosion of land by wind and water in Potohar area between Jhelum and Rawalpindi.

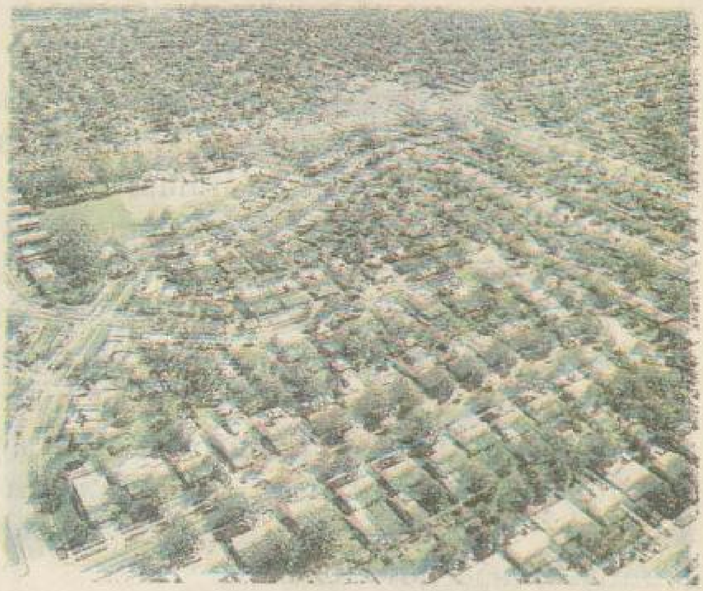


Fig. 15.5. Much of the world's population is crowded together in cities.

Other ways in which land may be mis-used is by rapid urbanization due to growth of cities, towns and suburbs (Fig. 10.5). Construction of factories, highways and mining for coal and other minerals.

Pollution of soil may also destroy its structure and fertility. Fertilizers greatly pollute soils. Intensified applications of nitrogenous fertilizers greatly affects the natural nitrogen cycle. Large quantities of nitrogen may be leached into water and air. Nitrate fertilizers, may also cause health hazards from excessive nitrates in food especially in leafy vegetables and in drinking water. Another aspect of soil pollution is the effect of insecticides and herbicides on soil flora and fauna especially when the pesticides are mixed with soil during cultivation. Some soil organisms are more sensitive and others relatively less to these soil poisons.

(IV) Wild Life

In a broad sense, wildlife refers to all non-cultivated plants and non-domesticated animals (Fig. 15.6). It has contributed significantly in the welfare and development of human society. Importance of game animals as a source of animal protein in supplementing human diet can hardly be ignored. Wild animals such as beavers, muskrats, seals, minks and foxes etc., are sources of precious skins for luxury furs and leather industry. Elephant tusks are used for the production of souvenirs and decoration pieces in many African countries. A wide variety of animal and plant products are used in cosmetics, perfumes and pharmaceuticals. Live animals for pet trade and zoos are other significant uses of wildlife. In general, wildlife is an important source of recreation and a major attraction for tourism in many African countries, especially Kenya.

From the ecosystem view point, all living organisms are interdependent. There is a delicate balance between living organisms and environment in any particular region. Man has been disturbing this balance since very long. In the past man considered that most of the wildlife were either useless or even harmful to him. He replaced the natural wildlife with communities of plants and animals which he considered useful. Keeping in view his ever-growing needs, he replaced the native plants of the region with wheat and other cultivated crops. He destroyed wolves, hawks, owls and snakes because he regarded them as his direct enemies. Man cut down forests to use the land for agriculture. Thus he destroyed the native plants and deprived the native animals of their habitat and food. Even today man is disturbing natural habitats, by building dams, draining swamps, mining for coal and other minerals and constructing highways. Thus man destroys the places where wild organisms live and reproduce. As a result these animals either die out or else are so reduced in their numbers as to be on the verge of extinction. These are known as the **endangered species.**

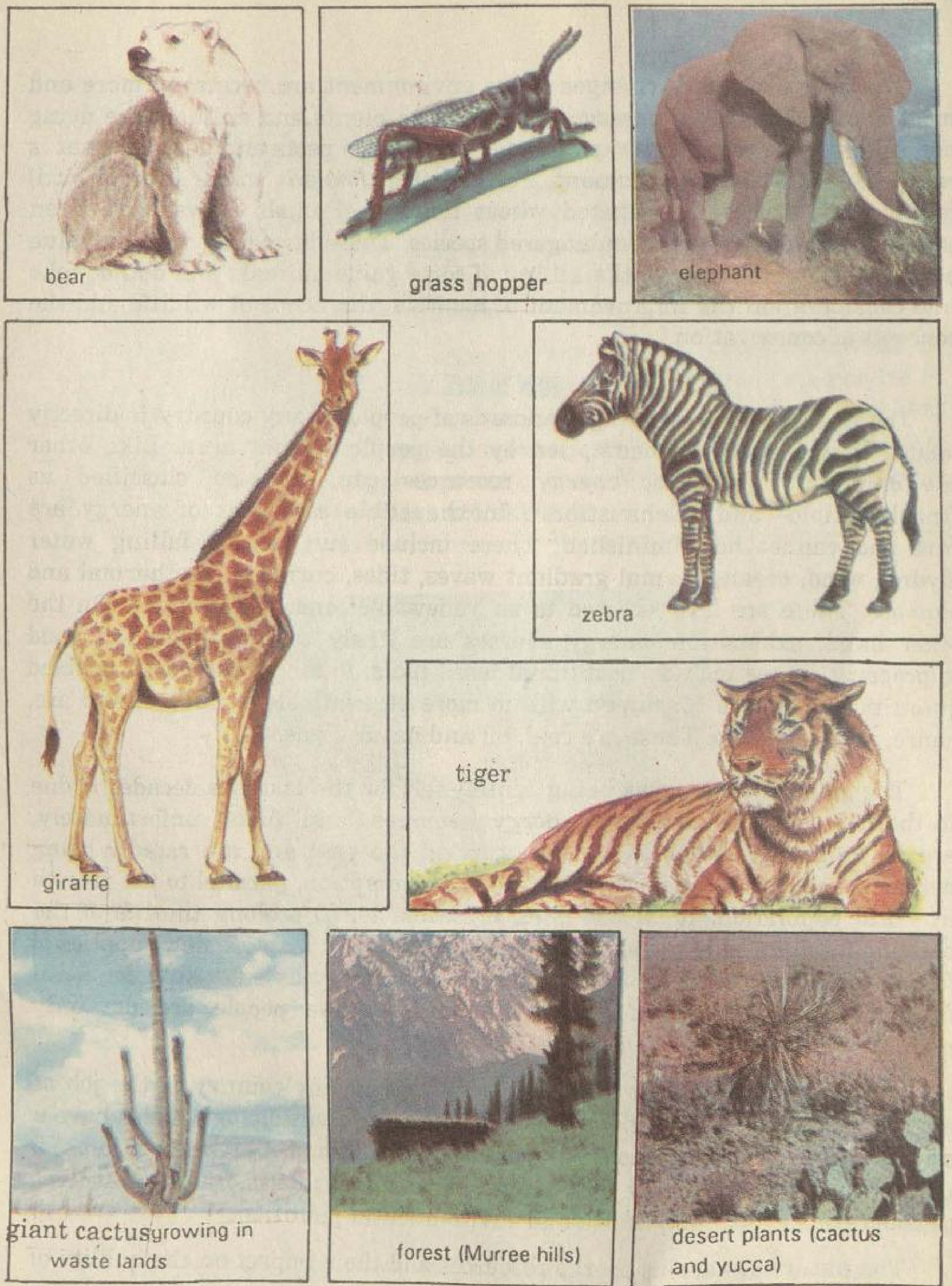

bear
grass hopper
elephant
giraffe
zebra
tiger
giant cactus growing in waste lands
forest (Murree hills)
desert plants (cactus and yucca)

Fig. 15.6. Wild Life: Some important fauna and flora

The effects of man's changes of the environment are becoming more and more apparent with the passage of time. Some plants and animals are dying out, others are multiplying rapidly and may become pests and destroy what is really useful in the environment. For example, *Phalaris minor* (dumbi sitti) has become a pest in irrigated wheat fields in Punjab. Laws have been promulgated to protect the endangered species. These laws have limited value because they only apply to the killing of some game animals and do not take into consideration the improvement of habitats, the needs of wildlife and the concepts of conservation.

ENERGY

The improvement of living standards of people in any country is directly related to the energy consumption by the people of that area. Like other environmental resources, energy resources can also be classified as "Inexhaustible" and "Exhaustible". Inexhaustible resources of energy are vast and cannot be diminished. These include sun (solar), falling water (hydro), wind, ocean-thermal gradient waves, tides, currents, geothermal and biomass. These are also reffered to as 'renewable' energy resources. On the other hand, exhaustible energy sources are likely to be depleted if used improperly. These include traditional fossil fuels, found in the earth in fixed quantity and if once consumed will no more be available in future, and are, hence, nonrenewable. These are coal, oil and natural gas.

The global energy crisis being acutely felt for the last two decades is due to the fact that the traditional energy resources (fossil fuels), unfortunately, are no longer as abundant as they were in the past and are rapidly being depleted, because of the increasing rate of consumption, parallel to the growth in world population. It is, therefore, desirable to, (i) prolong the life of the existing fossil fuels by reducing their consumption; (ii) explore new supplies of fossil fuels and (iii) develop other sources of energy as substitute for fossil fuels, so that the present living standards of the people are not only maintained but also improved.

Although development of energy resources in any country is the job of engineers, chemists, geologist and politicians, at present biologists also have a critical role to play in the context of environmental impact of exploitation of a particular source of energy. Any energy development decision often involves considerations of human health and environmental pollution.

The nature of various energy resources and their impact on the quality of the environment is briefly discussed below:

(I) Fossil Fuels

Coal, oil and gas are collectively known as **fossil fuels.** They supply us about 95% of our energy requirements needed in various transport systems, generation of electricity, industry and mechanized farming. They are indispensable for industrial development of a country. They are called fossil fuels because they are remains of plants and animals that lived millions of years ago and later due to global environmental changes became burried and fossilized in deeper layers of earth and sea.

Ever since, the discovery of coal, oil and gas as valuable sources of energy, man has become more and more dependent on them. This has led to extensive drilling, both on land and in sea for oil and gas and mining for coal around the world (Fig. 15.7). Pakistan is no exception. We have some supply of natural gas and have meagre deposits of coal. Extensive drilling for oil is being carried out in various regions of Pakistan.

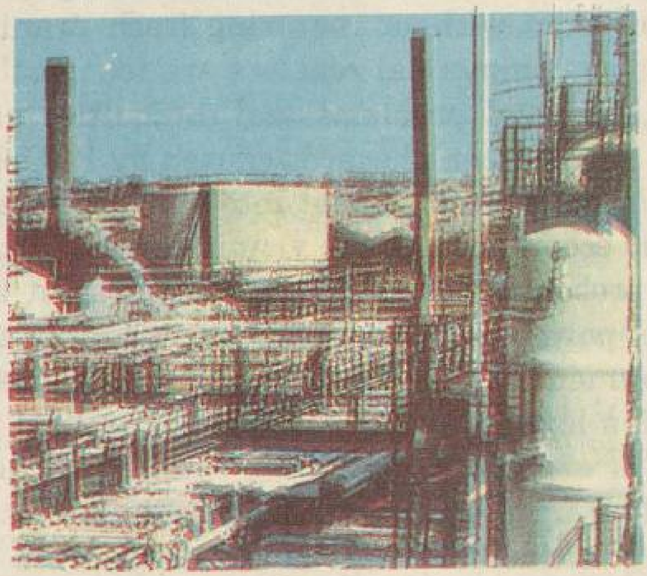


Fig. 15.7. National oil refinery, Karachi.

Although fairly cheap and easily available, exploitation of energy of fossil fuels is not free from environmental hazards. Burning of these fuels in ever-increasing number of automobiles and factories has overburdened the atmosphere with excessive quantities of carbon dioxide and a number of other toxic gases like carbon monoxide and oxides of nitrogen and sulfur, thus polluting the air we breathe. Furthermore, mining for coal and drilling for oil and gas can destroy valuable forest lands and wildlife habitats.

These fossil fuels are present in the earth in fixed and limited quantities and since their supplies are nonrenewable; they will exhaust sooner or later. It will certainly affect standards of life of future citizens. This necessitates the search for other sources of energy.

(II) Nuclear Energy

Splitting of the nucleus of a radioactive atom releases tremendous amount of energy, called as **nuclear or atomic energy.** It has been used by scientists to generate electricity in nuclear reactors. This process of "spliting of the atom" is known as fission. Nuclear fission reaction is the basis for running Nuclear Power Plants. Uranium 235 is the primary nuclear fuel used in the present day reactors. It is mined from common rocks containing uranium.

Nuclear energy is virtually inexhaustible source of energy. Nuclear fuel supplies though limited and nonrenewable but the breeder reactor technology could support electricity generation at a level much higher than the present level for thousands of years without requiring fresh uranium supplies. The present day water cooled commercial reactors are technically sound and safe to operate. However, the real problems and difficulties of depending upon nuclear energy lie in environment hazards caused by it. Operation of nuclear power plants release large amount of heat into air and water which can upset terrestrial and aquatic ecosystems in the vicinity of the nuclear power plants. However, the worst problem is that of disposal of solid and liquid wastes produced from these power plants. These wastes are radioactive and if released in the environment (i.e. land and water) continuously emit radiation, increasing the radiation level, thus causing environmental pollution. Human and other organisms, if exposed to radiation, show both short and long term consequences, depending upon the intensity of radiation. Sudden exposure to high radiation during accidental radiation leakage from a nuclear power plant, can disrupt and destroy living tissue, causing death within minute. Such a nuclear accident occurred in Soviet Union in 1986. When explosion in a nuclear reactor at Chernobyl Nuclear Power Plant released lethal radiations in the environment, that killed thousands of people in the area. Cancer of skin, bone marrow, lungs, as well as leukemia are some of the long term consequences of exposure to radiation. Strict precautionary measures are required to protect human and other life from the fatal effects of radioactivity in the environment. It is clear that nuclear power, with all its potentials, has some serious environmental problems. In Pakistan, at present, there is only one nuclear power plant at Karachi (Fig 15.8). It supplies nearly

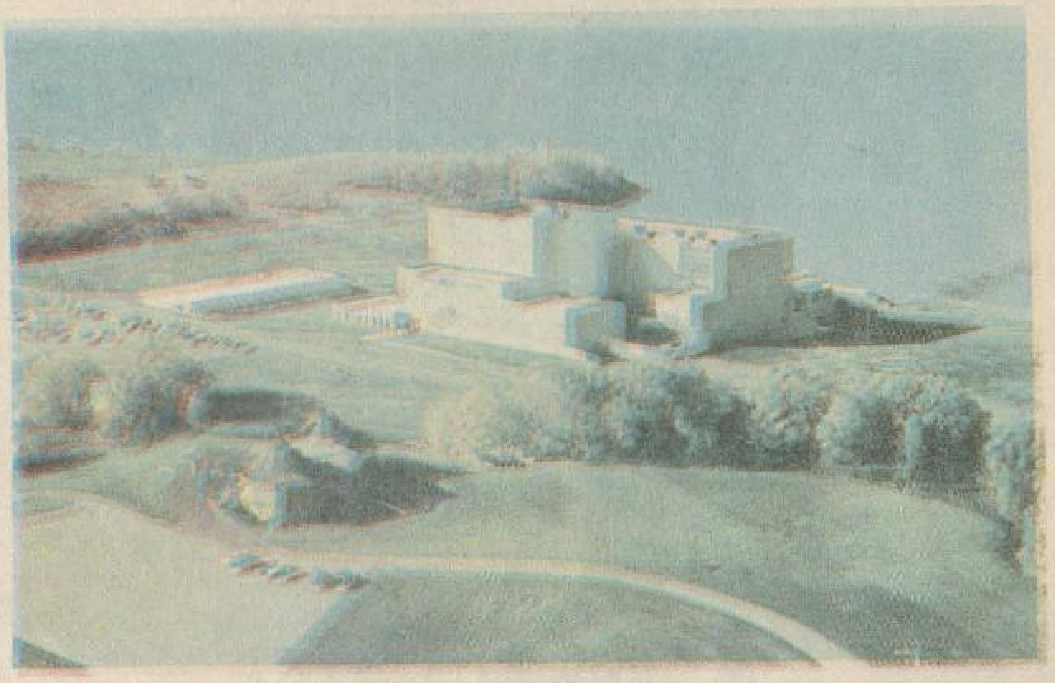


Fig. 15.8. Karachi nuclear power plant.

2% of nation's power requirements. Some more power plants are being planned to overcome energy crisis.

(III) Hydro-Electric Power

In this case, energy of falling water, is used to generate electricity. Hydro-electric power is produced more economically in mountainous regions or hilly areas of a country, where rivers make natural falls. Since rivers are seasonal and do not maintain a uniform flow of water throughout the year, this flow may be regulated by storing the river water in reservoirs (lakes), to continue power generation throughout the year (Fig. 15.9).

Hydro-electric power has many advantages as compared to other sources of energy. Unlike fossil and nuclear fuels the supply of falling water will never run out. As compared to fossil fuels, hydro-electric power is fairly clean, pollution free and less expensive. However, natural ecosystems, agricultural lands and wildlife habitats are destroyed when dams are built to develop lakes for water storage. Furthermore, life of these dams is limited and their power generation capacity is expected to be lost at the sites due to silting of water reservoirs. At present no real solution to this problem is known. In

15.9 Hoover Dam in Arizona. Water power has been used for many centuries.

Pakistan, hydroelectric power plants at Tarbela, Mangla and to some extent Warsak Dams are supplying a major part of nation's power requirements. More hydroelectric power plants are being planned to meet ever increasing demands of electricity.

(IV) Solar Energy

Sun is an infinite and inexhaustible source of energy which will be available for billions of years. The average flow of solar energy on earth's surface, keeping in view diurnal and seasonal variations, weather and latitudinal condition, is 180,000 kilowatts per square kilometer. It is much more than that normally used anywhere in the world.

Solar energy can be exploited in two ways. One way is to directly capture sunlight and use it directly in residential areas for heating of water, houses, schools or office buildings (Fig 15.10). It is economical as compared to electricity. Even solar air-conditioning of buildings is also being proposed in view of rising costs of electricity generation from fossil fuels and other sources.

The other method of exploiting solar energy is to use it to generate electricity which can be stored in batteries for commercial use in urban areas. Solar cells developed for this process are, however, much too expensive at this stage to be economically feasible. Solar power plants are in operation in certain countries of the world. A solar power plant is also being developed in Balochistan on experimental basis. There are, however, some technical problems concerning the economics and distribution of solar energy.

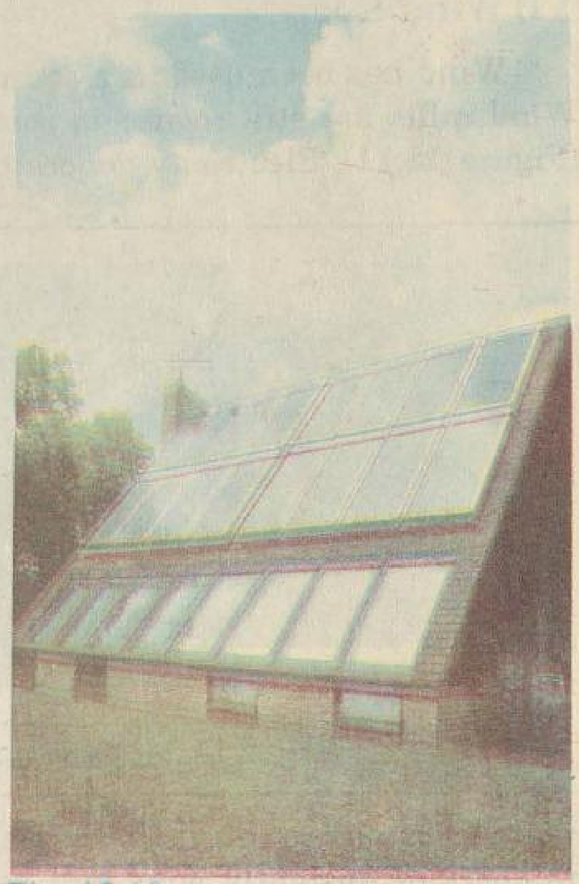


Fig. 15.10
A home with solar heating system.

(V) Geothermal Energy

Geothermal energy is produced due to natural radioactive decay in the earth's core, essentially working like a huge "nuclear reactor". In nature this energy comes to earth's surface as heat in the form of hot water springs, hot rocks or steam. Even in areas, where the heat of geothermal energy fails to reach the earth's surface, technology has been developed to drill deep into the earth to exploit it.

Geothermal power plant is based on conversion of geothermal heat into electricity. Only a modest amount of energy can be delivered by a geothermal power plant, as the temperature produced by geothermal heat is relatively low. In USA, geothermal power plants, using water of hot springs for generation of electricity, are in operation. Although, geothermal power plants are less expensive as compared to ordinary power plants using fossil fuels, they also create considerable air and heat pollution problems. Highly salty waste water produced during operation of such a plant is a source of environmental hazard. This saline water, also, corrodes the equipment of the power plants.

(VI) Wind Energy

Wind has been used as a source for power generation in the recent past. Wind mills are still in use in some European countries, especially Holland (Figure 15.11). Electricity generated by wind mills is only a fraction of that required by any country. Uncertainty of weather, visual pollution due to large numbers of unsightly wind-mill generators over vast area of land and high costs involved in their setting-up are major problems in the exploitation of this energy source.

Fig. 15.11 Modern windmills in southern California.

(VII) Solid Wastes

Solid wastes including municipal trash, paper and its products, discarded cartons, organic manures (cow dung), plastic and polythene materials, bottles and cans, wood trimmings, food, agricultural and industrial wastes, are produced in thousands of tons in every country (Fig. 15.12) and pose a new threat to man as they are source of pollution of land and water.

These solid wastes can be converted into gas or oil by the use of any of the three scientific processes i.e., hydrogenation, pyrolysis (destructive distillation) or bioconversion. Hydrogenation and pyrolysis processes are similar to those used for conversion of coal into synthetic oil and gas. Fluidized - bed incineraters have been developed, which burn solid wastes as high pressure. It produces hot gases; which can be used to generate high pressure. It produces hot gases, which can be used to generate electricity. Municipal wastes are useful solid wastes. It has been estimated that by burning 400 tons of municipal refuse 15,000 kilowatt electric power can be produced.

Fig. 15.12. Solid wastes.

Bioconversion in simple terms is the digestion of organic wastes by bacteria. Methane gas is produced during this process. It can be used as a fuel. In Pakistan biogas plants are being developed in villages to supply gas for domestic purpose.

There are several environmental problems involved in the use of solid wastes for fuel production. Environmental problems of sulfur emission, release of polluted water and disposal of organic sludge produced in bioconversion are to be overcome before this source of energy can be exploited.

(VIII) Ocean-Thermal Gradients

In tropical regions, temperature of surface water of oceans is about $25^{o}C$ and that at the depth of few hundred meters only $5^{o}C$. Thus an ocean thermal gradient develops and heat is conducted from regions of higher to lower temperature. Technology has been developed to use this difference in temperature to drive a turbine for generation of electricity. However, there are some environmental problems in the use of ocean thermal gradients as source of energy. Use of so many ocean thermal gradient power plants may change temperature of water of different regions of ocean to the disadvantage of marine life thus disturbing marine ecosystem with far reaching consequences.

(IX) Tidal Power

Tidal power can be used for large scale electricity generation. Direct use of tidal waves for this purpose is technically not feasible. A dam can be built on a bay that is filled and emptied at high and low tides. Such a dammed bay can then function like a regular hydroelectric power plant and the force of falling water can be used to drive turbine to generate electricity. (Fig. 15.13). However, only a few coastal areas of the world are suitable to harness tidal power. If any of these is located in some remote areas, then the cost of power transmission to industrial and other consumption centres will be quite high.

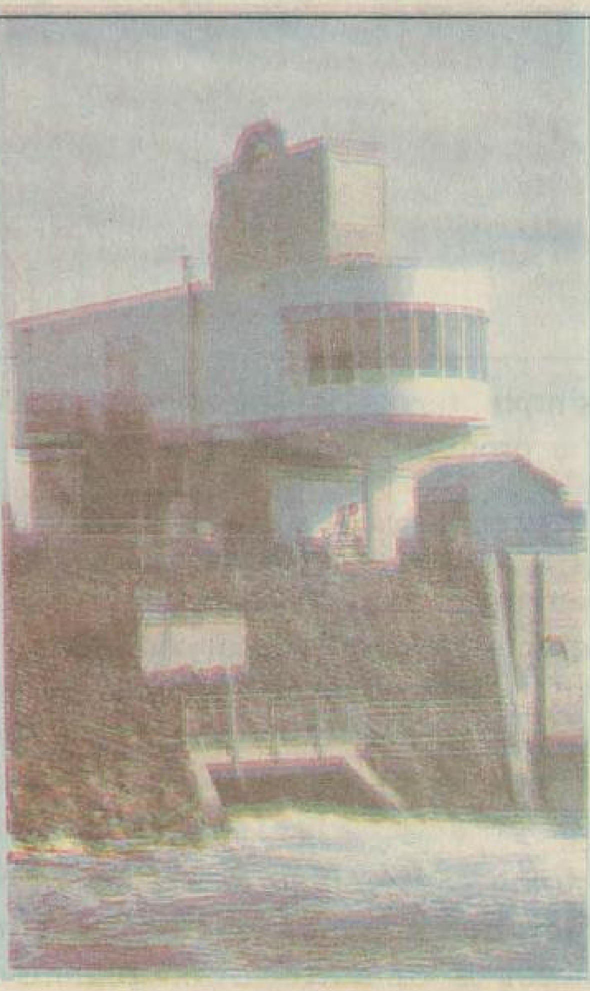


Fig. 15.13 Tidal power plant

(X) Energy Conservation

It refers to balanced and planned use of energy resources. Energy resources of most of the countries of the world especially the developing countries including Pakistan are limited. It is, therefore, important that there should be planned use of these resources so that their life is prolonged and supplies last for a longer period of time. Thus the energy saved is energy produced. In this sense, conservation is a unique source of energy, much different from the one's discussed above. In precise terms, conservation of energy is the potential to save energy by wise and balanced use of available resources. In view of international energy crisis, certain measures have been advised for conservation of energy. These are: (i) energy conservation, (ii) reduction in the use of energy for heating and cooling of homes and (iii) use of public transport system and car pools instead of personal cars, would be very effective in reducing energy consumption in transportation.

POPULATION AND FOOD

Food is a renewable resource due to continuous photosynthetic activity of producers in the global ecosystem of planet earth. This food is available to all animals in the ecosystem directly or indirectly through food webs. However, unlike other renewable resources such as water and air, food is exhaustable and limited in amount.

(I) Population Growth

Human population grows when more people are born each year than die. Furthermore, there is close relationship between human population growth and food availability. Studies have shown that for many thousands of years world population grew very slowly and in the year 1650 A.D it was only 550 million. It increased to 1000 million (1 billion) in 1825. In the twentieth century human population showed tremendous growth. It increased to 2 billion in the year 1927; 3 billion in 1960; 4 billion in 1975 and 5 billion in 1987. This sharp rise in population during twentieth century is shown in (Fig. 15.14). It may be noted from above that after 1650 population doubled in about 200 years and the doubling time decreased to 100 years after 1825. This may be attributed to food supplies and better health and medical facilities as a result of scientific and industrial revolution of 1850. From 1927 to 1975, population doubled in just 48 years. The United Nations estimates indicate that in the last 20 years, population of more developed countries increased only by 23% in comparison to 62% of the less developed countries. If these trends of population growth continue, the world population will increase to 7 billion by the year 2000 and 10 billion by 2020.

The population of Pakistan was 32.5 million people at the time of independence in 1947. It has increased to around 120 million in 1992, which is more than three times increase. During this period average life expectancy has risen from 37 years to 54 and infant mortality declined from 150 to 100

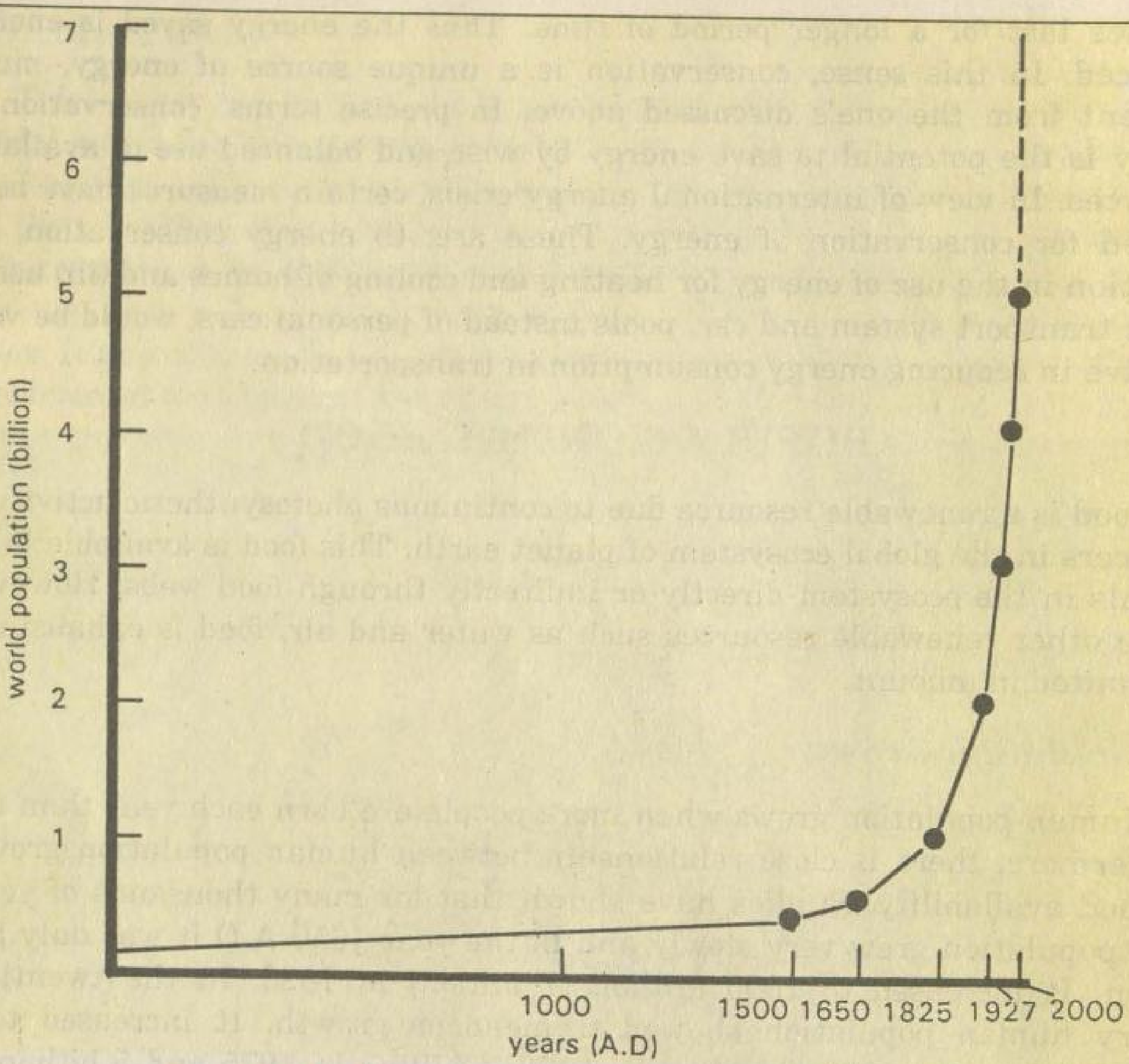


Fig. 15.14. Growth of the human population. The dotted part of the curve represents the projected future growth.

per 10,000 live births. The net growth rate is 3.1% per year and the population is expected to grow to 150-160 million people by the year 2000.

(II) Impact on Ecosystem

The rapid rate of human population growth is a matter of great concern to many. They believe that ever-increasing human population pressure may tax the ability of the natural cycles in the ecosystem to provide us essential resources necessary for life. There is a real danger that man may destroy the ecosystem that supports life on earth. One major way of man's effect on earth's ecosystems is through agriculture. Whenever lands of any region are cleared for cultivation of crops, the natural ecosystem of that region is destroyed. In crop lands, growth of single species (i.e., wheat, cotton, rice or corn) is promoted at the expense of species diversity of an ecosystem. In order to maximize crop yields, insecticides and herbicides are used to get rid of weeds, insect pests and other primary consumers. Thus normal interaction of organisms in a cropland food web are adversely affected. By eliminating a food web, fairly simple and efficient food chains are established and maximum food energy is diverted towards man directly through crops or indirectly through livestock (sheep, goat, cow etc.), which depend on crops for their food.

However, man does not realize that alteration of natural ecosystems through cultivation disturbs the balance of nature. Cultivated land in rainfed (barani) areas may be adversely affected by wind and water erosion, if not properly managed. Excessive ploughing of lands in arid regions, has resulted in the development of deserts. Repeated use of insecticide may eliminate a part of existing insect population, but the survivors become resistant to the insect sprays. Population of these resistant strains grow and may become even more difficult to eliminate. Elimination of secondary consumers (such as foxes, wolves, dogs and birds), which keep population of primary consumers (i.e., rabbits, rats, mice and insects) under control in croplands, result in the increase in the number of undesirable primary consumers. Thus, in an effort to grow more food, we disturb the balance of nature and stress our ecosystems.

(III) Increase in Food Production

Besides modifying food webs for increasing food production, there are two other ways of increasing food output: (i) by increasing area under cultivation as is being practised in most of the developing countries of the world, and (ii) by the use of genetically improved, high yielding and disease resistant varieties of wheat, rice, corn and other cereal crops. Use of nitrogenous fertilizer add more nitrogen, hence more proteins to plants. New breeds of cattle, buffalo, goat and sheep (primary consumers) make better use of the producers. Thus, a greater proportion of available energy, is stored in the tissues of the animals, subsequently available for human consumption.

At global level, the human population growth, especially in the developing countries, including Pakistan is the major cause for year to year increase in demand for food production. In rich countries e.g. West Germany, where population has stopped growing, it is the increased affluence and high per capita income, which is responsible for the increase in food consumption. Many scientist closely associated with green revolution, have emphasized that the new technologies in the field of agriculture did not solve the food problem.

They rather enabled us to buy some time (perhaps an additional 20-30 years) during which we should check the growth of the population of the world.

(IV) Human Diet

The recommended diet for an average young man should contain 2400 calories per day. It should include a reasonable balance of different kinds of foods, such as carbohydrates, fats, proteins and minerals, i.e., calcium, iron and vitamins. Protein is the most important nutrient needed for normal growth. Even after growth has stopped, protein is needed daily for repair and maintenance of body tissues. People taking food adequate in calories but deficient in protein may also be suffering from malnutrition. The mental and physical debility of most of the youngesters in the developing countries is due to protein deficiency. Daily protein intake rather then food of required calorific value is a better indicator of the quality of diet in the modern world.

United Nations estimates have shown that atleast 20% of the people living in developing countries are undernourished i.e. not getting minimum quantity of food needed. Atleast 60% are not getting minimum quality food (adequate in protein) needed for good health. This shows that about one third of the world's population is suffering from malnutrition if not hunger and complete starvation. On the contrary overeating or being obese is the problem of affluent societies. (Fig. 15.15).

Fig. 15.15. Victims of famine starving children.

(V) Possible Solutions

Though food is a renewable resource but the agricultural land needed to produce it, is limited in every country. It is believed that lands, most suitable for agriculture, are already under cultivation. In addition, rapid expansion of cities in the developing countries of the world (due to urbanization and industrialization) and the spread of deserts is decreasing the amount of land available for agriculture. Furthermore, putting new lands under cultivation is not so easy. It requires massive amounts of energy in the form of fertilizers, human and animals / mechanical labour and irrigation. Dams and canal networks developed for irrigation purposes in Pakistan and many other countries of the world create many environmental problems as salinity and water-logging. Irrigation life of dams, is very short and it may have many long term effects on the existing ecosystems of the region, when their reservoirs will be turned into deserts due to silting. It should be realized that in the face of prospects of increasing food deficit due to increase in population; increased resources utilization to bring more land under cultivation would also involve increasing environmental hazards. Thus there appears no way to solve problem of food, but to control human population and bring it to the level of resources available.

Scientists are also exploring other sources of food, not used extensively, so far. Japanese and others are studying the possibility of using seaweed (**kelp**) as source of food for people living in coastal regions. Some biologists believe that in future **kelp** farms will be cultivated and fish will be raised like cattle in such areas.

Food production can also be increased by preventing the loss of food through waste during harvesting and storage. Poor harvesting technique, inadequate storage facilities, presence of insects and rodents increase the food wastage. In certain parts of the world upto 30% of the harvest may become spoiled. In affluent families, especially in countries like Pakistan, wastage occurs, when more food is served than actually consumed. Reduction and prevention of wastage may well increase food supply.

Diseases of crop plants, especially of wheat, rice, corn and gram etc., is another source of food losses. Plant breeders are busy in developing disease resistant varieties of various crop plants to maximize their yield. The new technologies, like genetic engineering or recombinant DNA technology, are being extensively persued to create not only pest resistant or stress resistant varieties, but also nutrient rich crops.

Many scientists and others are worried due to the fact that even if ways and means are developed to supply adequate food to the growing world population, there are still other problems. There is problem of fresh water supply and limited amount of space, which our planet provides us to live. Our cities are already overcrowded. This crowding is associated with other problems such as land, water and air pollution, unemployment, poverty, lack of adequate housing, health, education and transport facilities. It is because of the reasons that many are compelled to believe that we have no option but to slow the population growth.

Many European countries have already stabilized their population since the past decade by reducing their birth rates. Countries like Great Britain, Sweden, Norway, Hungary, and Japan are nearing-zero rate of population growth. China has employed a variety of social measures to reduce the growth of its population. On the other hand, Asian countries like, India, Pakistan and Bangladesh have fastest growing populations of the world. Population growth rate of 3.1% per year in Pakistan is highest in the world. The success of family planning programmes in reducing birth rates in these countries is hardly visible. In case there is no substantial achievement in reducing the population growth rate in these countries, the battle to feed huge and rapidly increasing population of Asian countries may well be lost.

HEALTH AND DISEASE

Disease and starvation are two major natural forces which curtailed the growth of human populations in the past. Recent advances in medicine and agriculture have revolutionized human society. How far scientists succeed in protecting human populations from disease and hunger in future, is a big challange? Some general aspects of health problems in relation to nutrition and diseases are discussed here briefly.

(I) Health Problems

The major health problems faced by human population today, are nutritional deficiencies. Approximately one billion people in the world, are suffering from nutritional deficiency. People of India, Pakistan and Bangladesh in general, are worst affected by malnutrition. Lack of high quality protein such as egg, milk and meat in the diet, is the basic cause of nutritional deficiency. Minimum protein requirement for an average adult is between 37-62 gram per day, whereas in most poor countries, protein consumption per individual remains as low as 6-20 gram per day. Severely under-nourished children are easy victims of various diseases as they lack sufficient body resistance against them. According to FAO reports, nutritional deficiency is the major single cause of child mortality in poor countries. In Pakistan, 10 percent deaths of children may occur due to malnutrition.

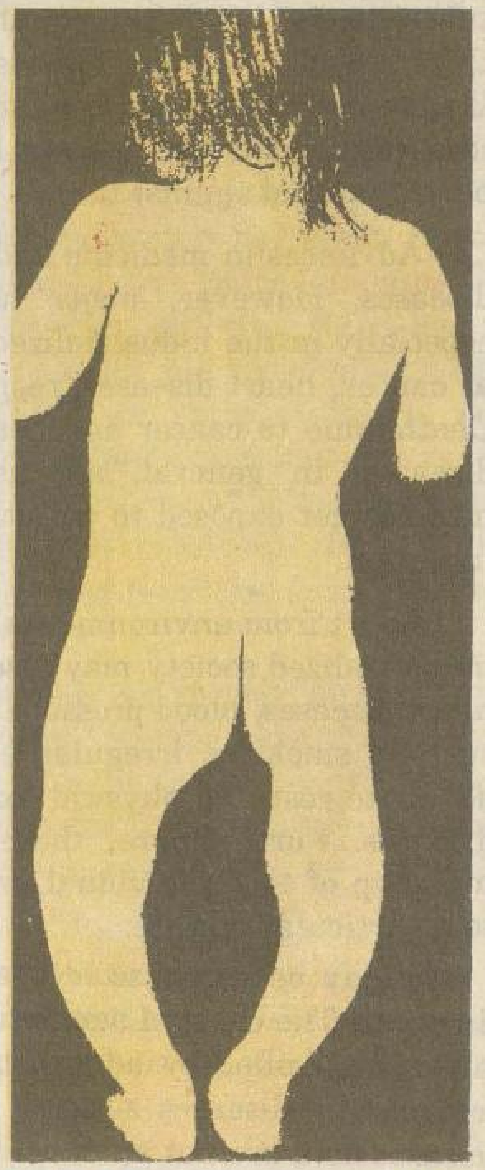


Fig. 15.16.
The bones of the child are bent as a result of a lack of calcium in the diet. This disease is called rickets.

Protein is important for mental and physical health and its deficiency in early childhood affects development of central nervous systems, thus reducing learning capacity of children. Besides proteins, diet may also be deficient in essential minerals as calcium, iodine and iron. Deficiency of these minerals may also cause some diseases. If children are fed on calcium deficient diet during early childhood, their bones remains soft and get easily deformed leading to a disease called **rickets** (Fig 15.16). Availability of iron in the diet is essential for red blood corpuscles and its deficiency causes anemia. Iodine deficiency causes malfunctioning of thyriod gland leading to the development of goitre which is common in northern part (Gilgit) of Pakistan. Similarly, vitamins are essential component of food and indispensible for good health. Vitamin A and iron-deficiency anemia continue to be major nutrition problem all over the world.

(II) Infectious Diseases

Human health suffers from a number of diseases caused by some bacteria, viruses or Protozoa. In the early period of 20th century some of these infectious diseases i.e. plague, small-pox, pneumonia, influenza and tuberculosis were the major causes of death. Scientists have been continuously struggling to control and eradicate these diseases. By the year 1980, small pox was totally eradicated from the world showing great success of scientists. Vaccines are also available for other diseases like diptheria, whooping cough, tetanus, measles, poliomyelitis and tuberculosis. In all the countries of the world and especially in developing third world countries infants are vaccinated against these diseases under United Nations sponsored Child Health Care programme. It is important that like small-pox, these diseases should also be eradicated and every body should be immunized against them.

Advances in medicine and science has controlled deaths due to infectious diseases. However, major health problems confronting human societies especially in the industrialized nations today, are degenerative diseases, such as cancer, heart diseases, respiratory disorders and cerebrovascular diseases. Deaths due to cancer and heart diseases are on the increase. Most of these diseases, in general, are associated with environmental pollution. The humans get exposed to pollutants through either skin contact, inhalation or ingestion.

Apart from environmental pollution, stresses and anxiety of fast life of an industrialized society may also significantly contribute in the development of heart diseases, blood pressure and other emotional disorders. Personal habits, such as smoking, irregular eating times, not eating balanced food, lack of adequate rest and physical exercise may also enhance the incidence of these diseases. Furthermore, these environmental factors interact with genetic make up of each individual, which determines the susceptibility or resistance to a particular disease.

It may be emphasized that the causes of infectious diseases are easy to pin point. The causual agents may be some bacteria, virus or protozoan, which can be controlled by administration of drugs. On the other hand, causes of present day diseases such as allergies, heart problems and cerebrovascular diseases etc., are not so clear. It is known that smoking increases individual's risk of developing lung cancer but then the other factors may also be involved as well. There are reports that some non-smokers may be even more susceptible to cigarette related lung cancer than the habitual smokers. Since the causes of present day degenerative diseases are not clearly established, consequently little is known about the effective control and cure of these diseases.

(III) Taking Care of Health

Extensive research programmes are being carried out in various leading laboratories of the world to find out causes and cures of heart diseases, cancer, Aids (acquired immuno deficiency syndrome) and other major diseases of today. Meanwhile best treatment is to adopt preventive measures against these diseases by improving general health. Regular habits, balanced diet, adequate rest, no smoking and regular exercise merit special consideration in this connection.

A balanced, nutritious diet is important for good health. Information on nutrition is available easily now-a-days and improving our diets is not at all difficult as the choice of food rests with us. A diet rich in protein and low in fat should be preferred. Fish is better source of protein than red meat. Butter is rich in saturated fat and if continuously consumed over years increases the risk of a heart attack. Margarine made from corn or sunflower oil is low in saturated fat and is a good substitute of butter. Whole grain bread and cereals are better than preparations from refined flour as many vitamins and minerals are lost during refining processes. Fruits and vegetables are ready sources of minerals and vitamins. Fruit juices are more nutritious than soft drinks. Experts emphasize that we should consume relatively more fruits, vegetables, fish, poultry, milk and whole grains and less fats, sugar and red meat.

Smoking is another major risk factor, contributing to poor health, lung caner, heart diseases and cerebrovascular diseases. Studies have shown that people who live in congested cities and smoke, run 10 times the risk of lung cancer, than do the village dewellers, who do not smoke. According to another report, a smoker runs a risk of reducing his life expectancy by about 12 minutes for every cigarette he smokes.

Rest is also essential for good health. A regular pattern of night sleep of six to nine hours (depending on individual's requirement), is more conducive for good health than a variable one with long hours of sleep one night and very little the next.

Constant stress and tension is another factor, silently contributing to increased risk of present-day-diseases. Every body has to face a certain amount of tension and anxiety in business, at office, college or at home. People resort to excessive smoking, drug abuse, drinking or over-eating in response to these tensions which aggravate the problem. Drug abuse causes mental and physical illness leading to innumerable social problems, accidents and suicides. It is advisable to learn to relax in the face of crisis and resolve tensions through some hobby or any other pass-time.

Our life-style also affects our health in many ways. Regular schedule of exercise is essential for physical fitness. Excercise strengthens our muscles, heart, lungs, arteries and accelerates the pace of blood circulation. Inactive life-styles contribute to obesity, high blood pressure and heart diseases.

It can be argued that by improving diet and life-style we can improve our health, but we seem to have little control on the deteriorating quality of the environment which is adversely affecting our health. It may, however be emphasized that strong public opinion and protests from scientists may force both the government and industrialists to control industrial pollution and the emission of poisonous gases into the atmosphere, thus deteriorating the quality of our water and air. Social organization should be developed at local, national and international level to build public opinion to play their role in protecting and preserving the environment.

QUESTIONS

1. What does environment provide us? How its quality has been degraded?
2. What are environmental resources? Give a brief account of three renewable resources and impact on society of their quality.
3. Give an account of air as a renewable environmental resource with special reference to acid air and greenhouse effect.
4. Write short notes on the following: (a) Wildlife, (b) Acid rains, (c) Greenhouse effect (d) Renewable and nonrenewable resources.
5. What do you mean by energy crisis? Discuss three major resources of energy in Pakistan and their environmental impact.
6. What are nonconventional resources of energy? Discuss their potentials and environmental impact.
7. What is nuclear energy? Discuss its advantage and disadvantages.
8. Discuss the impact of human population growth on the ecosystem. Why is it necessary to control human population growth?
9. Do you think that we can meet the demands of growing human population by growing more food? Discuss various possible solutions.
10. What are today's major human diseases? Why is it difficult to cure them like the diseases of the past?
11. Discuss various measures we should adopt to look after our health under conditions of deteriorating environmental quality.

12. Write short notes on the following:

    (a) Energy conservation, (b) Human population growth, (c) Human diet and nutritional deficiencies.

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BEHAVIOUR 16

Behaviour is defined as a change in response to stimulus. In other words animal behaviour is the sum of every thing that animals do, i.e. flying, walking, sitting, sleeping, eating, mating and rearing young ones, etc. Ethologists (those who are interested in studying animal behaviour) have evolved different methods for studying behaviour of animals in nature and under laboratory conditions.

There are two approaches to the study of behaviour: (a) physiological approach, and (b) psychological approach. Physiologists are interested in the mechanisms and try to give explanation in terms of the functioning of the nervous system. Psychologists, on the other hand, are interested in studying factors in an animal's environment and history which affect the development and performance of behaviour.

Nearly all the behaviours, we observe in animals are adaptive. Animal behaviour can be explained in two ways: (1) The animal may be born with the right responses built in the nervous system as part of its inherited structure. For example, honey-bees inherit the ability to form wings and wing muscles for flight; they inherit the tendency to fly towards flowers to seek nectar and pollen. Such responses are popularly called **instinctive.** Instinctive behaviour evolves gradually, as do structural features, and natural selection modifies it to fit the environment. (2) An animal may be born with few inherited responses but also with an ability to modify its behaviour in the light of its experience as it grows up. This is called **learning.** Instinct and learning both ensure adaptive behaviour, the former by selection operating during the history of the species, the later during the history of the individual.

Instinct can equip an animal with a series of responses. This is advantageous for animals with short life spans and with little or no parental care. For example, a female digger wasp emerges from her underground pupa in spring, after the death of her parents in the previous summer. After emergence she mates with the male wasp, prepares a nest, hunts and kills caterpillars, stores them in the nest, lays eggs on these caterpillars and then closes the nest. The adult female dies after egg laying, but the young ones that come out of the eggs start feeding on the caterpillars killed by their mother before death. All this must be completed within a few weeks and they are done by instinct. If the female, which lives for a short time, had to learn every thing from the very beginning, then it would be impossible to perform these duties.

On the other hand the lion cub is quite helpless, and is fed by the mother until it can move. It is gradually introduced to solid food. It has opportunities to watch and copy its parents as they capture prey. The cub may catch first small live prey when six month old. Its behaviour and methods of hunting according to circumstances throughout its life.

The digger wasp which must rely on preset instinctive behaviour and the lion who can learn represent two extremes on the behavioural scale. But infact digger wasp can and must learn many things during its brief life. For example, the exact locality of its nest because it has to return to the nest after its hunting trip. Similarly young lion possesses some predatory tendencies which are certainly instinctive.

Behaviour Patterns

Professor Allen made a study of the behaviour of the red-winged blackbirds which inhabit swamps. He noticed that the blackbirds do different things at different seasons of the year, and this permits a clear cut recognition of different kinds of adaptive behaviour. Comparing these with the behaviour of the other species, a list of nine important general kinds of behaviour have been developed:

1. Ingestive Behaviour

As a flock of blackbirds feed in the fields a first and very important kind of adaptation can be recognized. This may be called by the simple name of eating behaviour (Fig. 16.1) Many animals get most or all of their food in liquid form. Since the same organs are involved in eating and drinking and the behaviour is very similar, it is convenient to use a broad term, **ingestive behaviour.**

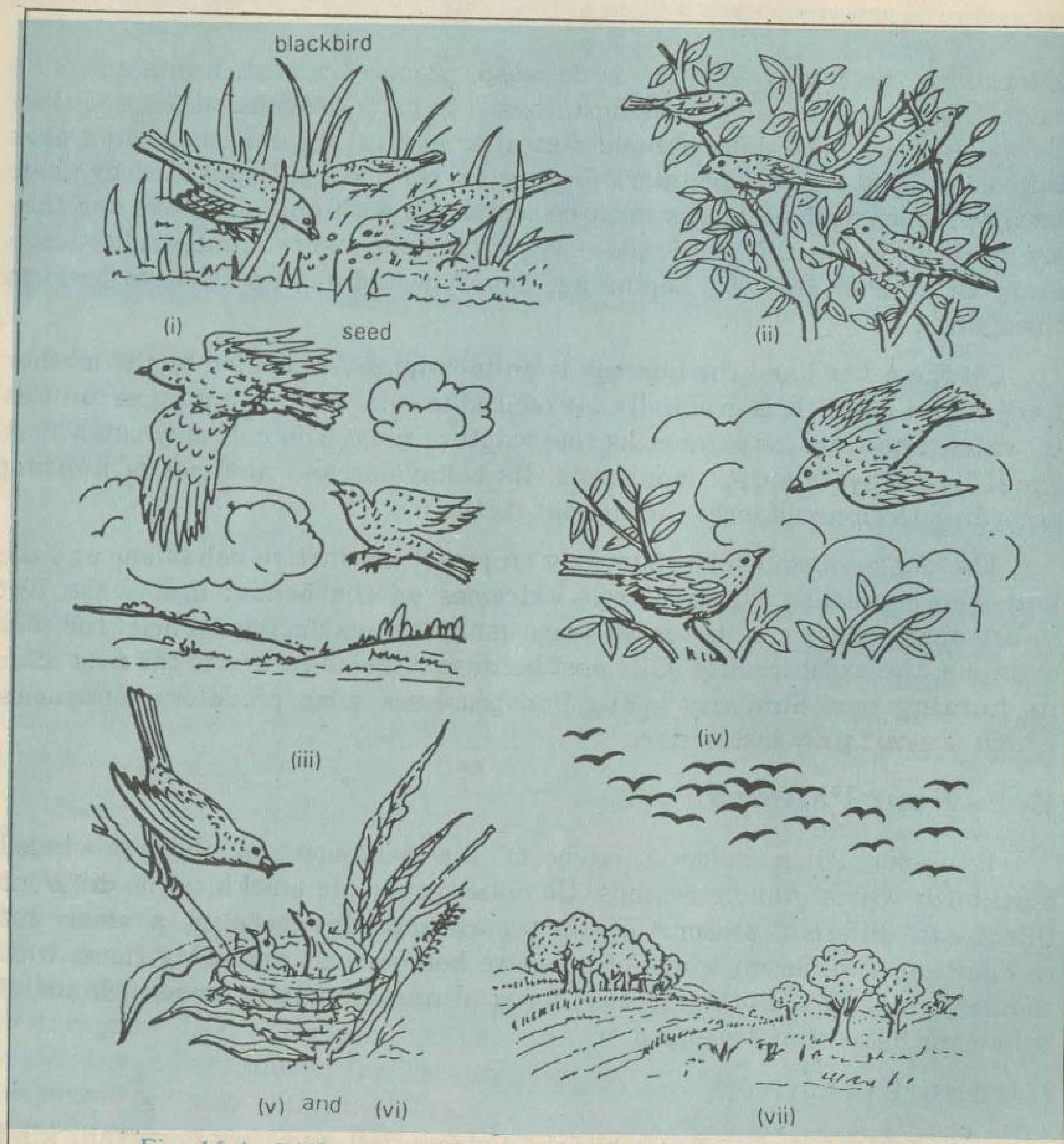

Fig. 16.1. Different type of adaptive behaviour seen in blackbird.

(i) ingestive behaviour, the black birds feed on grain and seed.

(ii) shelter-seeking behaviour

(iii) agonistic behaviour, as a crow flies over the territory of the blackbird, the males rise and fly at him aggressively.

(iv) sexual behaviour

(v) and (vi) care giving and care-soliciting behaviour.

(vii) allelomimetic behaviour

2. Shelter-Seeking Behaviour

Another general type of adaptation is seen as blackbirds come to roost at night. They often prefer trees which have thicker foliage and branches, permitting the birds to roost close together in protected spots. This tendency to seek out optimum environmental conditions and to avoid dangerous and injurious ones is found in almost all animals and may be called **shelter seeking.**

3. Agonistic Behaviour

One of the first thing which the male blackbirds do upon their return from south is to start fighting off intruders. The eventual result of the fight is that one of the birds escapes from the other. The behaviour of both may be included under the general term, **agonistic behaviour.** In other animals the defeated individual does not always attempt to escape. When mice fight, one of them may simply hold up his paws in a defensive way or become completely passive. Any sort of adaptation which is connected with a contest or conflict between two animals, whether fighting or escaping, may be included under this term.

4. Sexual Behaviour

Once the blackbird males have established their territories by agonistic behaviour, the females arrive and there begins the rapid pursuit which is characteristic of the courtship behaviour of perching birds. Finally the female accepts the male and actual mating takes place. There is no difficulty in recognizing this behaviour as **sexual behaviour,** which includes courtships, coition and any other related behaviour.

5. Care Giving Behaviour

The natural consequences of sexual behaviour is that young blackbirds eventually appear. They are at first unable to take care of themselves. This care is given by the parents and begins long before the eggs hatch. After mating, a nest is built, the eggs are laid and the female sits upon them until they hatch. Then the young are fed chiefly on insects, which both parents catch. All this behaviour has been described as the giving of care and attention, and by some authors it has been called **attentive behaviour.**

6. Care-Soliciting Behaviour

After the young birds are hatched, they begin to show some of the major patterns of behaviour themselves, and one of the first of these is ingestive behaviour. Along with this they begin to do things which are not characteristic of adults, making chirping noises and holding their heads up in the air with gaping beaks. This behaviour consists essentially of calling for care and attention. It may be called **infantile behaviour.**

7. *Eliminative Behaviour*

The young birds release the faeces and urine in pellets surrounded by a membrane, and the parent birds lift these out of the nest as part of their care-giving behaviour. This is called **eliminative behaviour.** The general effect is to keep the nest clean.

8.\ Allelomimetic Behaviour

After the young birds leave the nest they show tendency to fly together in flocks with wonderfully integrated movement (Fig. 16.2). The appearance of the flock during the flight roughly looks like a great bird. In flocking behaviour of blackbirds (and in some others), it is evident that the animals are responding to each other rather than to a single model. Even when a leader is present, it always pays some attention to the behaviour of the followers. The behaviour always seems to involve some degree of mutual stimulation, and the term **allelomimetic** has been build up of two Greek words meaning **"mutual"** and **"mimicking".**

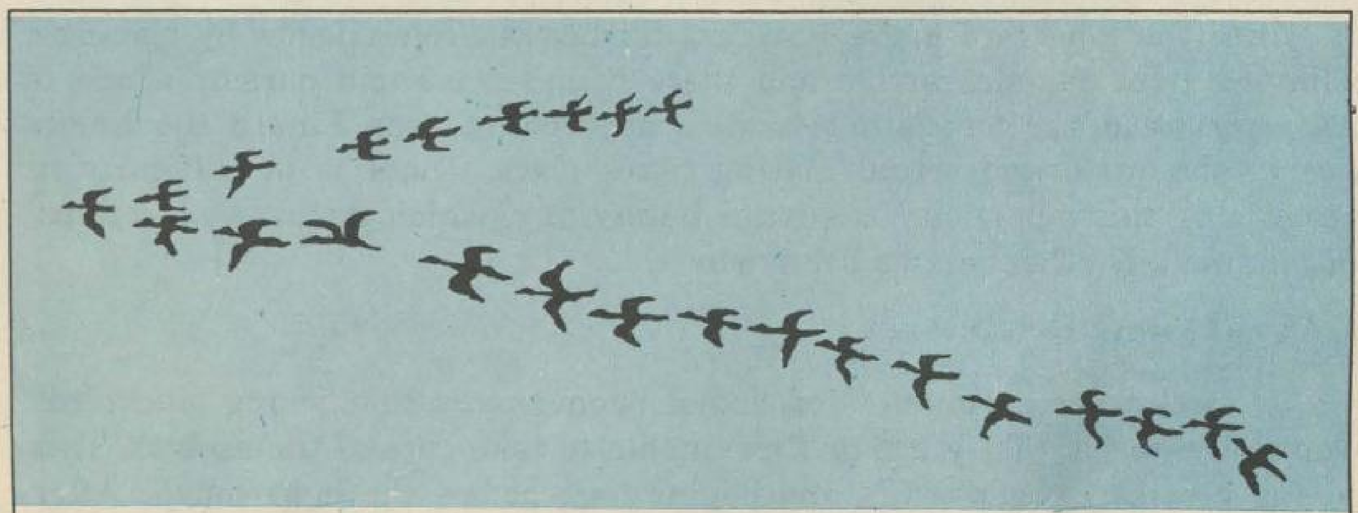

Fig. 16.2. Allelomimetic behaviour of Geese.

9. Investigative Behaviour

This kind of adjustment is not particularly obvious in blackbirds, which have good eyes and can observe their surroundings at a glance. Animals which have hands like racoons or monkeys, will pick up a strange object, turn it over, as they look at it, and they may also smell it or taste it. All this may be called **investigative behaviour.**

Learning Behaviour

The most general definition of learning is the modification of behaviour by previous experience. For example, when an animal is repeatedly placed in the same situation and stimulated; its later behaviour is affected by what has happened before. Thorpe has defined learning as that process which manifests itself by adaptive changes in individual behaviour as a result of experience. This definition draws attention to two important features. Firstly, learning normally results in adaptive changes which equip an animal with a set of adaptive responses to its environment. Secondly, learning is a process which cannot be measured directly, we measure what has been remembered as a result of learning. Thorpe classified the **learning behaviours** as:

1. Habituation

It is the simplest form of learning. Habituation does not involve acquisition of new responses but the loss of old ones. If an animal is repeatedly given a stimulus which is not associated with any reward or punishment, it ceases to respond. For example, a snail crawling across a sheet of glass retracts into its shell when the glass is tapped. After a pause it emerges and continues moving; a second tap causes retraction again but it emerges more quickly. Ultimately the tapping has no effect and the snail ceases to respond.

2. Conditioned Reflex Type I

The term conditioned reflex is inseparable from the name of the Russian Physiologist, I.P. Pavlov who performed classical experiments with dogs. Dogs normally secrete saliva when they see or smell food. Pavlov found that he could condition a dog to secrete saliva when a bell was rung just at the same time or just before food was given to the dog. After this combination of stimuli (bell ringing and presentation of meat) had been repeated, the dog secreted saliva whenever the bell was rung even if the meat was not given. The stimulus (of bell ringing) which produces a response(salivation) in the dog is known as **conditioned stimulus** and the response is known as **conditioned response.** This has been acquired through learning.

3. Conditioned Reflex Type II (Trial and Error)

In the **conditioned reflex type I** animal learns to respond to stimuli which are reinforced or rewarded. Suppose, instead of ringing a bell to the dog on Pavlov's stand (a stand designed to hold the dog) we lift its left front foot and then blow meat powder into its mouth. After a few trials the dog spontaneously lifts its foot when hungry. This type of learning has been called as **conditioned reflex type II**, but in this simple form it probably never occurs in nature where animals are freely moving about. A more natural situation is to reward some posture or act which is performed spontaneously in the first place. Thorndike used various problem boxes in his pioneer experiments on learning. One of these shown in (Fig. 16.3).

It is a cage which can be opened from inside only by depressing the lever. A cat is shut in and tries hard to escape. It moves about restlessly and after a time by chance it steps on the lever and the door opens. The second trial may be a repetition of the first but soon cat concentrates more attention on the lever and eventually it moves swiftly across the box and presses the lever as soon as it is confined or shut. The name 'trial and error' obviously fits this type of learning very well.

4. Latent Learning

Thorpe defines latent learning as the association of indifferent stimuli or situations without patent reward. Suppose we put a maze(Maze is a network

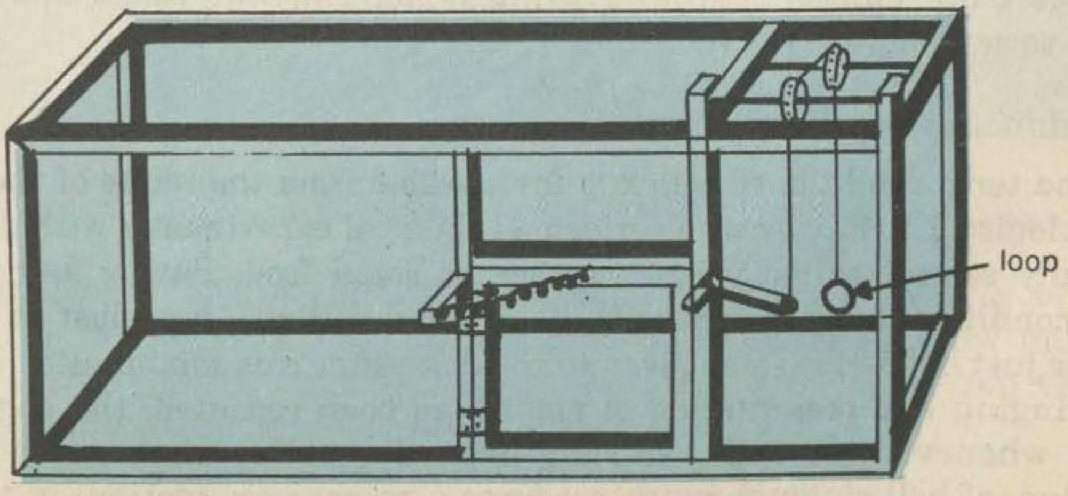

Fig. 16.3. One of Thorndike's Problem boxes

of Paths or a sort of problem box. One of the problem boxes is shown in (Fig 16.3.) For instance, a cat is confined inside the box or cage and must learn to pull the loop to open the door) up against a rat's home cage so that he can wander into it at will. The rat is not hungry or thirsty, nor does he find any food maze, but he explores through it, sniffing into corners ultimately returning to his own cage.Does he learn anything about the maze as he explores? The test comes when we train our rat to run through the maze when hungry to get a food reward at the other end. Does he perform better than a rat put hungry into the maze for the first time. If so then his previous learning was **"latent"** in that it was not revealed until we gave him a chance to put it to good use in finding food.

5. Insight Learning

Insight learning appears to be the highest form of learning. The classic example of insight in animals came initially from the work of Kohler on chimpanzees. Presented with a bunch of bananas too high to reach they would pile up boxes to make a stand for themselves or fit two sticks together in order to pull down the bananas. This indicates that these animals like many others have the ability for reasoning and thinking. Often the chimpanzees arrived at this solution quite suddenly although they benefited by previous experience of playing with boxes and sticks(latent learning) and showed considerable trial and error when actually building a stable pile of boxes.

6. Imprinting

Spalding found that chicks, that are 2 or 3 days old, would follow any moving object. Lorenz described imprinting as a unique learning process whereby the young of precocial birds (those that can walk at hatching and do not stay in the nest) form an attachment with a mother figure (Fig.16.4).

Normally of course, this is their real mother, but they will become attached to almost any moving object and subsequently treat it as mother. Lorenz considered that imprinting, unlike other forms of learning, was irreversible. It is restricted to a brief sensitive period, just after hatching.

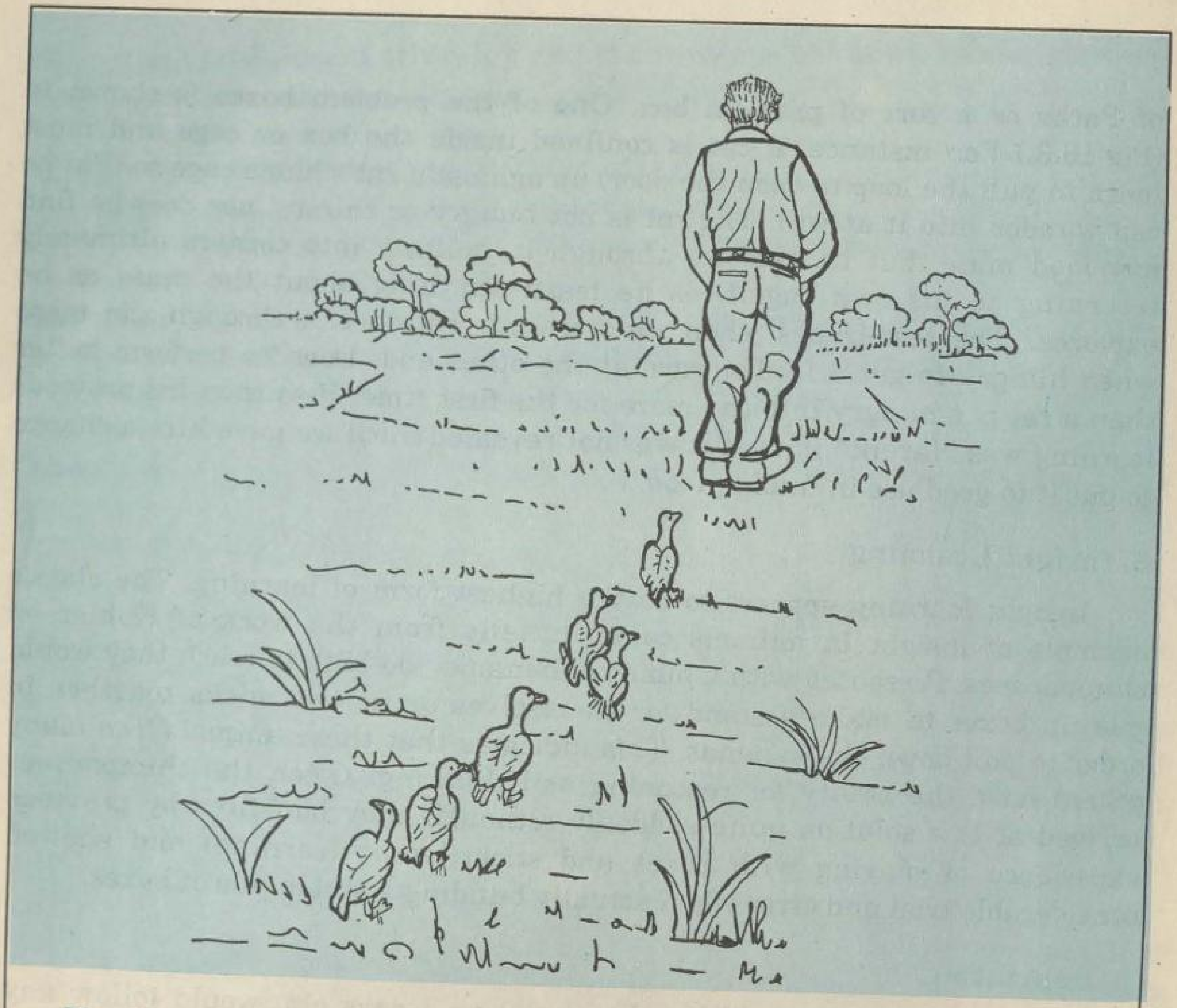

Fig. 16.4. Precocial birds can be socialized or imprinted so that they follow a human being rather than natural mother.

Social Behaviour

Schjelderup-Ebbe studied the social life of hens. He was able to identify different type of behaviour in hens. The hens did a great deal of pecking and threatening as they fed and walked around the yard. He noticed that in each conflict between two hens one always pecked and the other submitted without fighting back. The first hen was dominant over the second and their behaviour was called a **dominance-subordinate relationship.** When he described relationships between all the members of a flock, he saw the whole group organized into a "peck order" or dominance hierarchy(Fig 16.5).

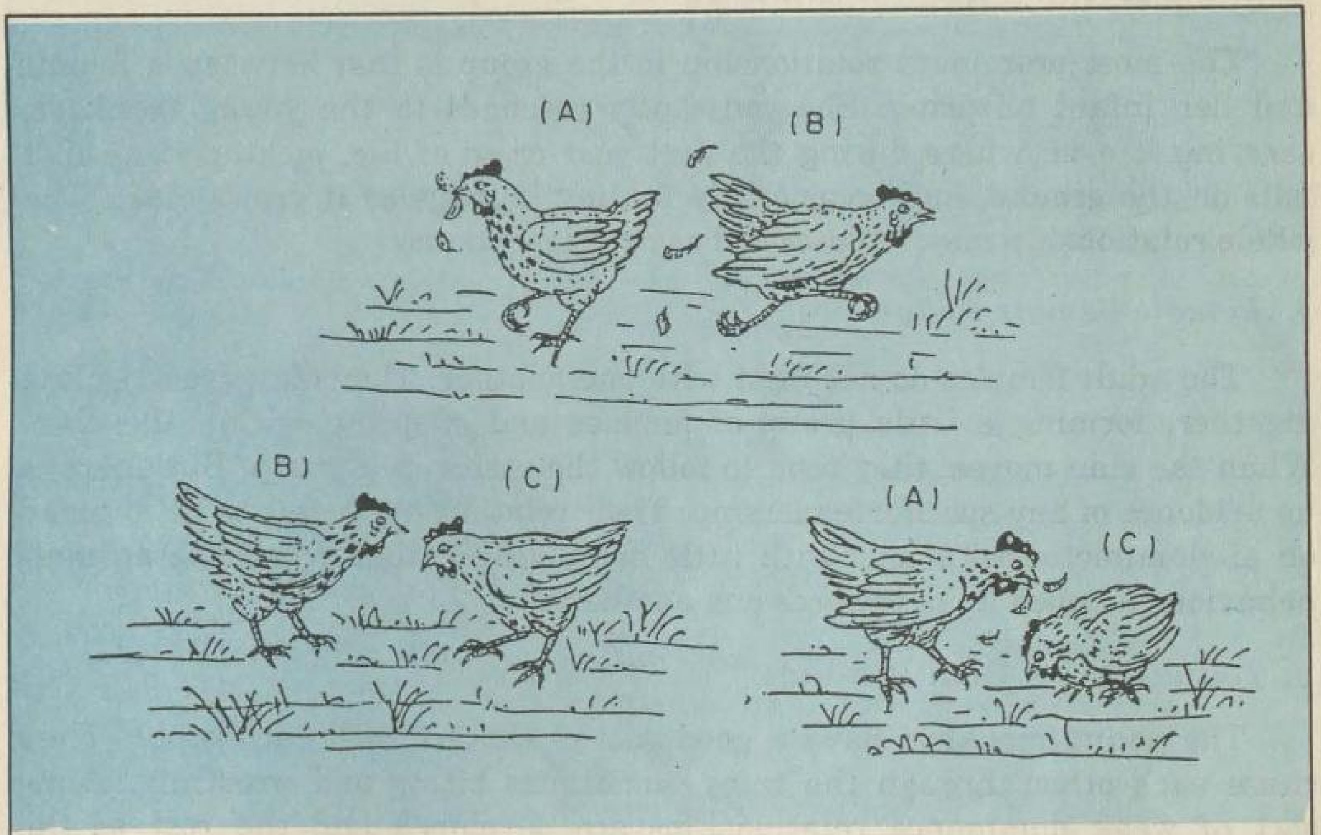

Fig. 16.5. Dominance relationship in group of three hens. Above, A attacks B and pulls out feathers. B quawaks and runs away. Left B threatens C, who dodges and crouches. Right, A pecks C, who erouches deeply.

The Organization of An Animal Society

Carpenter(1934) studied wild population of howling monkeys. He presented one of the best general studies on social organization of higher animals. Carpenter studied the daily cycle of behaviour of monkeys. He found that a group of howling monkeys usually sleep all the night in a tree. Early in the morning they get up move around until they find a tree with food in it. Then they settle down to feed for an hour or two on the fruit, twigs and leaves. During the middle of the day they rest for a few hours, then move on in another good place in the late afternoon. As darkness comes, they settle down for the night until the next morning. Howling monkeys show all the general types of behavioural adaptations: ingestive and eliminative behaviour, investigative behaviour and all the rest: these type of social behaviours are organized into definite social relationship.

1. Female-Young Relationships

The most prominent relationship in the group is that between a female and her infant offspring. She constantly responds to the young monkeys, carrying it everywhere during the first year or so of life, picking it up if it falls on the ground, and occasionally feeding it twigs as it grows older. The whole relationship may be described as care-dependency.

2. *Female-Female Relationships*

The adult females do not fight with one another. They stay usually close together, forming a little group of females and offspring within the clan. When the clan moves, they tend to follow the males in a group. But there is no evidence of any specific leadership. Their relationship seems to be founded on allelomimetic behaviour with little or no differentiation, all the animals behaviour is much alike towards one another.

3. Young-Young Relationships

The young monkeys have a good deal of contact with each other. They chase each other through the trees, sometimes biting and wrestling. Some sort of weak dominance relationships are developed and the rest of the behaviour is of undifferentiated allelomimetic type.

4. Male-Female Relationships

The females have a true oestrous period which lasts several days. When a female is in heat, she will approach any nearby male and initiate sexual behaviour. There is no sexual jealousy or that one male is preferred over another. The sexual relationship in howling monkeys are, therefore, temporary and non-specific. When the group moves as a whole, the males always take the lead,a general leader-follower relationship exists between the two sexes.

5. Male-Young Relationships

The old males are usually indifferent to the young. But if a young **monkey (Fig. 16.6) falls out of a tree, the males** become much excited, and the whole group will howl until it is rescued. In addition, the males will sometimes pick up the young monkeys if the mother is unable to do it. This behaviour is an evidence for a weak care dependency relationship between males and young.

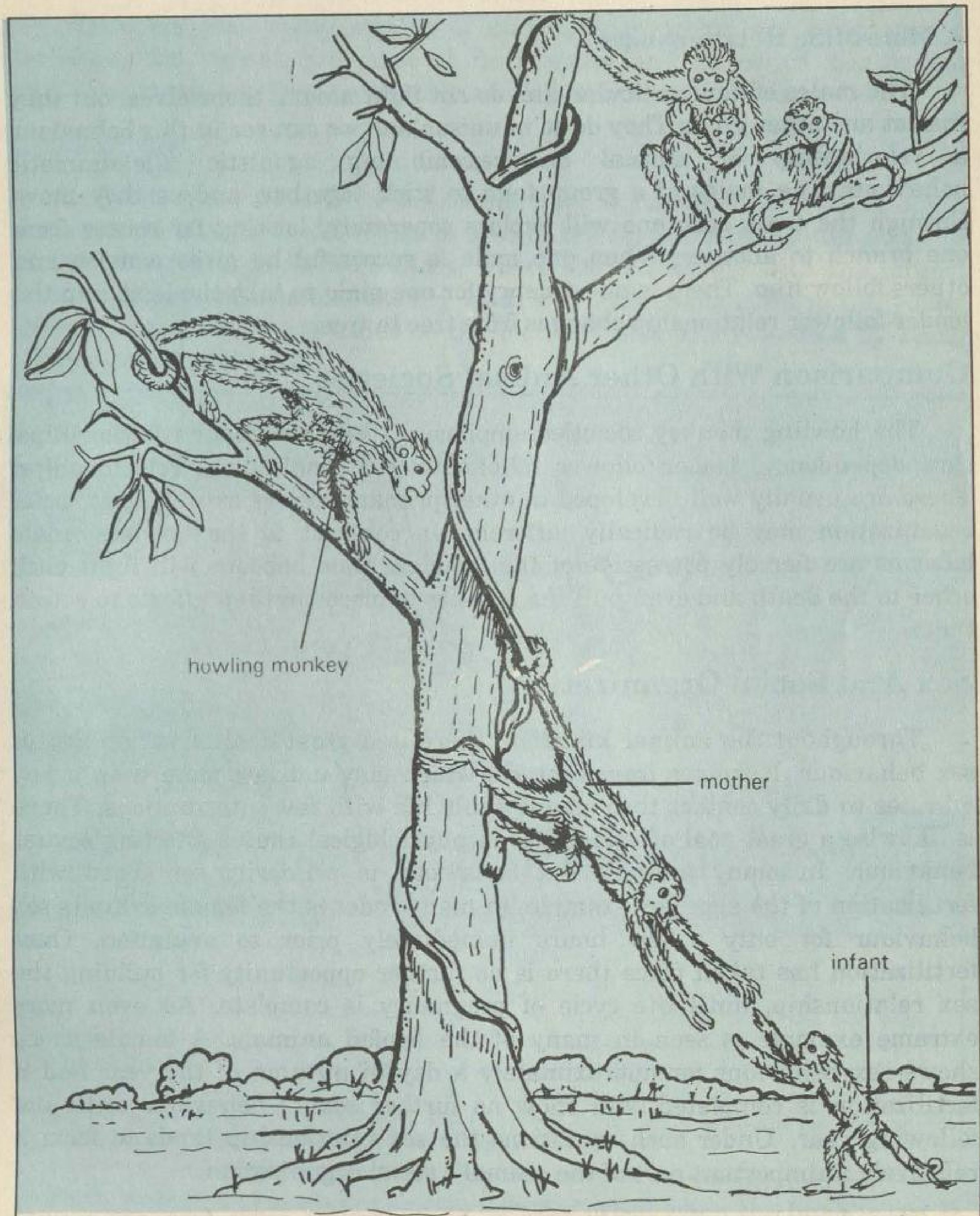
howling monkey
mother
infant

Fig. 16.6. Social behaviour in howling monkeys. An infant has fallen to the ground and its mother goes down to rescue it while a male howls from a nearby branch.

6. Male-Male Relationships

The males of any particular clan do not fight among themselves, but they roar at any other group.They do so in unison and we can see in this behaviour a relationship of mutual defence,combining agonistic allelomimetic behaviour. The males of a group tend to stick together, and as they move through the trees each one will explore separately, looking for routes from one branch to another. When one male is successful he gives a noise and others follow him. There is no tendency for one male to take the lead, and the leader-follower relationship changes from tree to tree.

Comparison With Other Animal Societies

The howling monkey societies emphasize three behaviour relationships: care dependency, leader-follower (allelomimetic), and sexual relationships. These are usually well developed in other primate species as well. But social organization may be radically different. In contrast to the howlers, male baboons are fiercely possessive of the females. Male baboons will fight each other to the death and even pull the females to pieces in their efforts to retain them.

Sex And Social Organization

Throughout the animal kingdom, there is a great deal of variability in sex behaviour. It ranges from contacts which may not last more than a few minutes to daily contact throughout adult life with few interruptions. There is likewise a great deal of variability in physiological causes affecting sexual behaviour. In many animals sex behaviour is primarily concerned with fertilization of the egg. For example, in many rodents the female exhibits sex behaviour for only a few hours immediately prior to ovulation. Once fertilization has taken place there is no further opportunity for building the sex relationship, until the cycle of pregnancy is complete. An even more extreme example is seen in many of the hoofed animals. A female sheep shows sex behaviour for approximately a day in autumn of the year and if fertilization is completed, will show no further sexual behaviour until the following year. Under such conditions the sex relationship tends to form a relatively unimportant part of the animal's social organization.

The physiology of reproduction in birds require more frequent sexual behaviour. Most birds lay several eggs and repeated fertilization is necessary. Consequently, mating behaviour goes on throughout the laying season, and sexual behaviour forms an important part of male-female relationship.

There are also many species of mammals in which sex behaviour is prolonged far beyond the need of fertilization and in which the sexual relationship tends to become a stable and important part of a society.

Leadership

In howling monkeys there is a tendency for the males to lead the females, although no one particular male is always the leader. Exactly the opposite tendency is found in flock of sheep, where the old female with the largest number of descendants consistently leads the flock. Among sheep the young lamb is constantly being called to the mother's side and rewarded by being allowed to nurse (Fig 16.7).

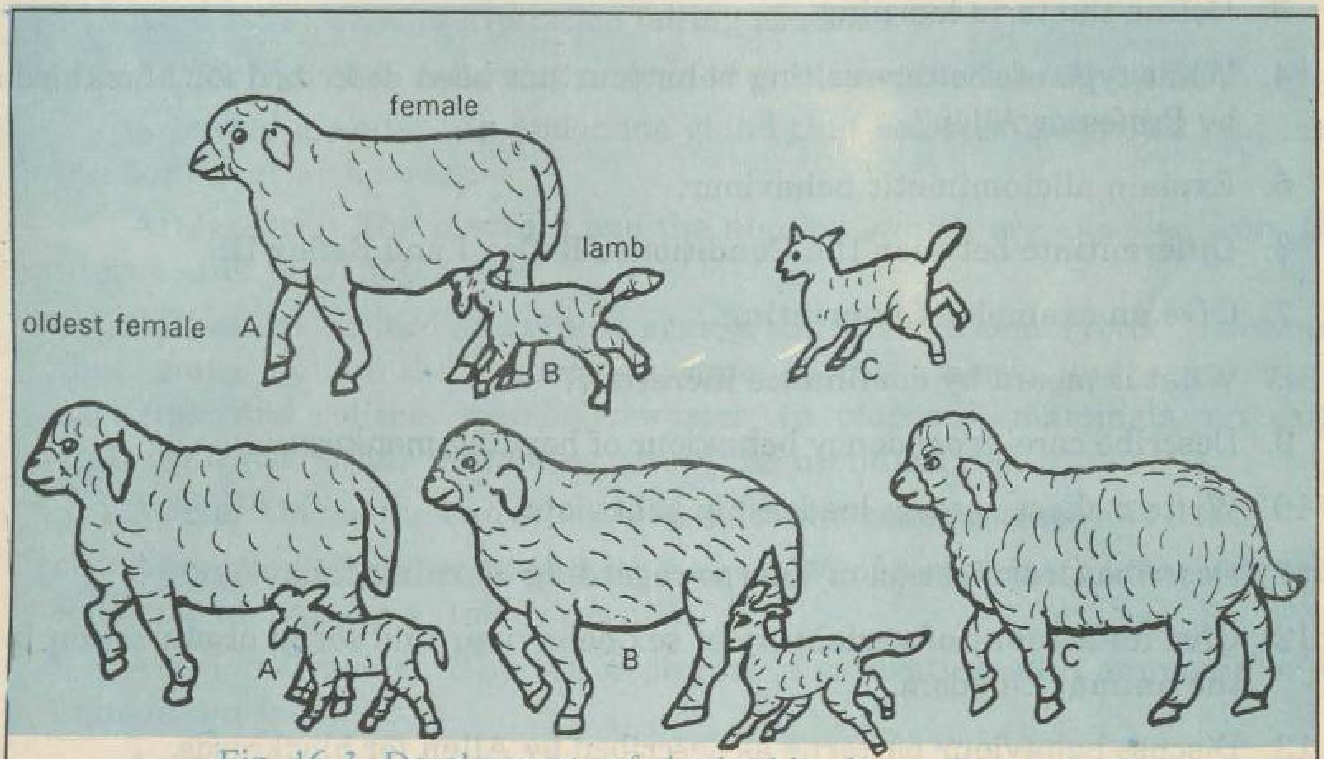

Fig. 16.7. Development of leadership in a flock of sheep.

Above, first year. A female followed by her twin lambs, one male and one female, Below, second year. The same female leads, followed closely by her female lamb of the year before. Each of them in turn is closely followed by a new lamb. The male sheep born in the previous year now brings up the rear. The young lambs form a habit of following their own mothers and this habit continues even into adult life, so that the oldest females tend to be the leaders of the flock.

Both mother and lamb are emotionally disturbed when the lamb is lost.It is possible that the emotions of anxiety and fear contribute to the tendency of the lamb to follow and that they make it a more lasting relationship than otherwise would be expected.

QUESTIONS

1. What is meant by behaviour?
2. What are instinctive responses? Give an example.
3. Define the term learning.
4. What type of shelter-seeking behaviour has been described for blackbirds by Professor Allen?
5. Explain allelomimetic behaviour.
6. Differentiate between the Conditioned Reflex I and Reflex II.
7. Give an example of imprinting.
8. What is meant by dominance hierarchy?
9. Describe care-dependency behaviour of howling monkeys.
10. Write a short note on leadership behaviour.
11. Describe classification of Thorpe regarding learning behaviour.
12. Give an account of variability of sex behaviour and social organization in the animal kingdom.
13. Discuss behaviour patterns as described by Allen for blackbirds.
14. Give an account of the social organization of the howling Monkeys.

☆☆☆☆☆

Glossary

A

Abiotic factor: A physical factor of the environment, such as water, air, light or temperature.

ABO blood group: A group of blood types (A, B, AB and O). Each type is identified by the presence of certain antigens on the surface of red blood cells.

Abscisic acid: An organic compound that influences the shedding of leaves and the seasonal slowing down of plant activities.

Acid rain: Acid precipitation falling as rain.

Actin: A widely occurring protein that is essential for cell motility.

Adrenal glands: An endocrine gland that secretes hormones that help the body deal with stress.

Afterbirth: The placenta and the amnion, which are expelled from the uterus after birth of the baby.

Allantois: In bird and reptile eggs, a sac like extraembryonic membrane that grows out of the digestive system of the embryo and controls gas exchange and collects metabolic wastes; in placental mammals, an extra embryonic membrane that forms part of the umbilical cord.

Allele: One of the two or more forms of the gene for a specific trait.

Allergy: A disorder caused by the release of histamine by the body cells following an antigen-antibody reaction.

Ammonification: The act or process of saturating with ammonia or an ammonium salts.

Amnion: In both shelled eggs and mammals, a fluid filled extraembryonic sac that surrounds the embryo, provides a watery environment and protects the embryo.

Analogous structures: Structures found in different types of organisms that are similar in function or outward appearance, but are dissimilar in basic structure or embryonic development.

Anticodon: A sequence of three bases on a tRNA molecule that pairs with the complementary, three-nucleotide codon of a mRNA molecule during protein synthesis.

Aorta: The major artery carrying oxygenated blood away from the heart.

Appendix: A small, fingerlike pouch found where the small intestine joins the large intestine.

Autonomic nervous system: A division of the peripheral nervous system consisting of motor fibres from the brain and spinal cord that serve the internal organs of the body; not under voluntary control.

Autosome: A chromosome other than a sex chromosome.

B

Ball and socket joint: A joint that permits movement in all directions.

Behaviour: The series of activities performed by an organism in response to stimuli.

Biome: A large geographical region showing a particular type of climax vegetation.

Biosphere: Living component of the planet earth.

Biotic factor: An organism in an environment and its effects on other living things.

Blastopore: The opening in a gastrula created by the gastrulation process; becomes an opening to the digestive system in the adult organism.

Blastula (pl blastulae): A stage of development in which the embryo consists of a single layer of cells surrounding a fluid filled cavity.

Bowman's capsule: A double walled, cup-shaped structure surrounding the glomerulus in the kidney.

Brachiation: To move by a swinging motion of the arms, as in certain monkeys.

C

Camouflage: A protective adaptation that enables an organism to visually blend into the environment.

Carbon cycle: The pathways by which carbon is circulated through the biosphere.

Central nervous system: The division of the nervous system that includes the brain and spinal cord.

Cerebellum (pl cerebella): A part of the brain located below the rear part of the cerebrum coordinating voluntary movements.

Chorion: The membrane that surrounds the embryo and the other extraembryonic membranes in mammals, birds and reptiles.

Chromatography: A process used to repeat and analyze mixtures of chemical substances.

Chromosomal mutation: A change in chromosome structure, resulting in new gene combinations.

Codon: A group of three bases in a mRNA molecule that specifies a particular amino acid.

Commensalism: A type of symbiotic relationship in which one organism benefits from the association and the other is not affected.

Community: All the populations of different species of animals and plants within a given area.

Connecting link: Graded series or intermediate stages leading from an ancient form to the modern form.

Corpus luteum: A progesterone-secreting yellow body in the ovary, formed when luteinizing hormone causes a ruptured follicle to fill with cells.

Correlation: The process of matching by which geologists determine the relative ages of rock layers and fossils in a local region.

Crop rotation: A method of farming in which different crops are grown on a field in successive years to prevent the reduction of soil nutrients.

Cytokinesis: The division of the cytoplasm of the cell after mitosis or meiosis; the cell divides into two parts, each containing one of the newly formed nuclei and half of the other contents of the parent cell.

D

Deletion: A type of chromosomal alternations in which a portion of a chromosome and the genes it contains is lost.

Dominance hierarchy: A ranking within a group of animals that is established through fighting or displays of aggression.

Dominant species: The species that exert the greatest effects on the environment and on other members of the community.

Dominant trait: The trait that appears in the offspring of a cross between two pure individuals showing contrast-ing forms of the trait.

E

Ecosystem: A community including all the component organisms together with the elastic environment forming an interacting system in any area.

Ecological niche: The role of an organism in the environment, its activities and relationships to the biotic and abiotic environment.

Ectoderm: The outer layer of cells in a simple animal or embryo, one of the germ layers of an animal embryo.

Effector: A muscle or gland, responds to a stimulus.

Egestion: The elimination of undigested material from the digestive tract.

Embryo: A multicellular organism in the early stages of development.

Embryonic induction: The process by which one group of cells (the organizer) induces another group of cells to differentiate.

Endangered species: A species explosed to danger of extinction.

Endocrine glands: A ductless gland.

Endoskeleton: A skeleton composed of bone or cartilage located within the body walls.

Epididymis: A storage area for sperm on the upper, rear part of the testis.

Epiphyte: A plant growing upon, but not receiving its nourishment from, another plant.

Epiglottis: A flap of tissue that covers the trachea during swallowing, so that food passes only into the oesophagus.

Epithelial tissue: A type of tissue that covers body surfaces and lines body cavities and organs.

Erosion: The removal of upper layer of soil by the action of wind and or water.

Erythrocyte: A hemoglobin-containing cell in blood that carries oxygen to the body tissues and carbon dioxide to the lungs; red blood cells.

Esophagus (pl. esophagi): The tube that is the passage way for food from the mouth to the stomach.

Estrogen: A hormone secreted by the ovaries that promotes development of female secondary sex characteristics and regulates the reproductive cycle.

Ethology: Study of animal behaviour.

Evolution: The theory that life arose by natural processes at an early stage of the earth's history and that complex organisms developed from simple organisms by a process of gradual change.

Excretion: The process by which the wastes of cellular metabolism are removed from an organism.

Exhalation: The phase of breathing in which air is expelled from the lungs.

Exoskeleton: A skeleton found on the outside of the body, enclosing the soft parts.

External fertilization: The process in which eggs are fertilized outside the body of the female.

F

Feces: Undigested and indigestible food material that is solidified in the large intestine and then eliminated from the body.

Fetus: The developing body about the second month of pregnancy.

Follicle: A structure in the ovary in which the mature egg develops.

Food chain: A series of organisms through which food energy is passed in an ecosystem.

Food web: A complex relationship formed by interconnecting and overlapping food chains in an ecosystem.

Foot: A large ventral, muscular structure that functions in locomotion in mollusks.

Fossil: The remains or traces of an extinct organism.

Faternal twins: Two individuals formed when two eggs are fertilized at the same time twins that are genetically different.

G

Gall bladder: The organ that stores bile produced by the lever.

Ganglion: A group of cell bodies and interneurons that switch, relay, and coordinate nerve impulses.

Gastric juice: The digestive secretion of glands in the stomach, containing hydrochloric acid and pepsin.

Gastrovascular cavity: The internal body cavity of a coelentrate..

Gastrula (p. gastrulae): In animals, an early stage of embryonic development during which the second germ layer is formed.

Gastrulation: The process in which the cells on one side of a blastula move in to form the two layered gastrula.

Gene: A distinct unit of heredity material found in chromosomes; a sequence of nucleotides in DNA that codes for a particular tRNA, rRNA or polypeptide.

Gene linkage: Genes located on the same chromosomes; they are not independently assorted but instead are generally distributed together during meiosis.

Gene mutation: A change in the sequence of the bases in a gene, which changes the structure of the polypeptide that the gene codes for.

Gene pool: The total of all the alleles in a population.

Genetic drift: A condition in which one allele becomes fixed in a population.

Genetic engineering: The process of producing altered DNA usually by breaking a DNA molecule and inserting new genes.

Genetics: The branch of biology concerned with the ways in which hereditary information is transmitted from parents to offspring.

Genotype: The genetic makeup of an individual.

Germ layers: The three embryonic cell layers — the ectoderm, mesoderm and endoderm — that give rise to all tissues and organs of animals.

Gestation period: The length of a pregnancy.

Gizzard: In birds and many invertebrates, a thick walled grinding organ that crushes food released from the crop.

Glomerulus (pl. glomeruli): A cluster of capillaries in the nephron of a kidney.

Glucagon: The hormone secreted by the pancreas that increases the blood glucose level.

Gonad: In animals, a specialized organ in which gametes develop.

Grassland: A biome in which there is not enough rainfall to support trees and the dominant form of vegetation is grasses, prairie.

Greenhouse effect: Increased heating of earth's atmosphere due to accumulation of carbon dioxide.

Gullet: The part of the paramecium where food particles enter the cell.

H

Habit: Learned behaviour that becomes automatic.

Habitat: The particular part of the environment in which an organism lives.

Habituation: The simplest type of learning; the animal learns not to respond to repeated "unimportant" stimuli.

Haploid: Having half the diploid number of chromosomes; n or monoploid.

Hardy-Weinberg law: The principle that sexual reproduction by itself does not change allele frequencies in a population.

Halophytes: A plant that grow in saline soil.

Helix: A shape like a coiled spring used to describe the structure of DNA molecule.

Hemoglobin: A red, iron-containing pigment in the red blood cells of vertebrates that increases the oxygen carrying capacity of the blood.

Hemophilia: A hereditary disease in which one or more of the clotting factors are missing from the blood.

Hepatic-portal circulation: A subdivision of the systemic circulation that transports blood from the digestive tract to the liver.

Hermaphrodite: An individual organism that possesses both testes and ovaries.

Heterozygous: Having two different alleles for a trait.

Hibernation: A state of winter inactivity of some animals.

Hinge joint: A joint that permits back and forth motion in one plane, such as the elbow and knee.

Homeostasis: The condition of a stabie internal environment in an organism.

Homologous pair: A pair of chromosomes having the same size and shape and carrying alleles for the same traits.

Homologous structures: Structures found in different kinds of organisms that have the same basic arrangement of parts and a similar pattern of embryonic development.

Homozygous: Having two identical alleles for a trait.

Hormone: A substance that is secreted by a gland directly into the bloodstream and that produces a specific effect on a particular tissue.

Humus: The dark, rich organic matter in topsoil formed from the decay of dead plants and animals.

Hybrid: An individual that is heterozygous for a particular trait; an individual produced by a cross between members of two closely related species.

Hydrosere: The series of changes in the succession of plant communities found in water.

Hypothalamus: The part of the human brain located below the thalamus; controls body temperature, blood pressure, and emotions.

I

Identical twins: Two individuals formed when one fertilized egg divides in half at an early stage of development, producing two organisms with the same genetic makeup.

Immovable joint: A joint in which the bones are fitted tightly together and cannot move.

Immunity: The ability of the body to resist a disease.

Implantation: The attachment of the embryo to the uterine lining, in placental mammals.

Imprint: A type of fossil formed when an impression made in mud by a living thing is preserved when the mud is transformed into rock.

Imprinting: In some animals, the forming of an attachment to an organism, object, or other environmental factor soon after hatching or birth.

Impulse: A region of electrical and chemical change that passes along the cell membrane of a neuron.

Inbreeding: A breeding method in which closely related individuals are mated to retain or strengthen certain desirable traits.

Incomplete dominance: A type of inheritance in which neither of a pair of contrasting alleles is dominant over the other and the heterozygous individual is intermediate in phenotype; blending inheritance.

Independent assortment: The principle of genetics stating that the alleles of genes on nonhomologous chromosomes are inherited independently of one another.

Industrial melanism: The development of dark coloured organisms in a population exposed to severe, soot-laden air pollution.

Inferior vena cava: A large vein that collects blood from the lower half of the body and returns it to the right atrium of the heart.

Inhalation: The phase of breathing in which air is drawn into the lungs.

Innate behaviour: Behaviour determined by heredity.

Instinct: A complex, inborn behaviour pattern.

Interferon: A protein produced by body cells in response to attack by viruses.

Internal fertilization: The process in which eggs are fertilized within the body of the female.

Interneuron: A neuron that relays impulses from one neuron to another.

Intertidal zone: The biome along the ocean shoreline that is covered by water at high tide and uncovered at low tide.

Intestinal juice: A secretion of the cells of the walls of the small intestine, containing digestive enzymes.

Intestine: The organ in which most digestion and the absorption of food occurs.

Intraspecific competition: Competition between members of the same species in an ecosystem.

Inversion: A type of chromosomal alternation in which a portion of a chromosome is rotated, resulting in the reversal of the order of the genes in that segment.

Iris: The round coloured part of the eye formed from the choroid layer; controls the size of the pupil.

Islets of langerhans: The endocrine protein of the pancreas, consisting of clusters of hormone-secreting cells.

J

Joint: A point in the skeleton where bones meet.

K

Kidney: One of a pair of organs in vertebrates that excrete nitrogenous wastes and regulate the bloods chemical balance.

L

Labor: The slow rhythmic contractions of the uterine muscles during child birth.

Lacteal: A small lymph vessel found in the centre of a villus.

Large intestines: The final section of the digestive tract, it serves three functions reabsorption of water, absorption of vitamins, and the elimination of undigested and indigestible material from the digestive tract.

Larva (pl larvae): An early development stage of some animals after hatching; must undergo metamorphosis to reach the adult form.

Larynx: The voice box, connects the pharynx with the trachea.

Law of dominance: The principle of genetics stating that when organisms pure for contrasting traits are crossed, all their offspring will show the dominant trait.

Law of segregation: The genetic principle stating that the alleles of a gene occur in pairs and are separated from each other during meiosis and are recombined at fertilization.

Law of independent assortment: When a pair of traits are followed in the same cross they are found to be inherited independent of one another.

Learned behaviour: Behaviour that develops as a result of experience.

Lens: In the eye, the structure behind the iris that focusses light on the retina.

Leukocyte: A nucleated blood cell that serves as part of the body defense against disease, white blood cell.

Ligament: A tough, fibrous band of connective tissue that holds the bones together at a movable joint.

Linkage: The location of two or more genes on the same chromosome so that the two characteristics are passed on together from parent to offspring.

Littoral zone: The biome between the intertidal zone and the continental shelf; the water is relatively shallow and light reaches the ocean floor.

Lymph: The fluid inside the lymph vessels.

Lymph nodes: A lymphatic gland that plays an important role in the body defense against disease.

Lymphatic system: A system of vessels that returns excess fluid and proteins from the intercellular spaces to the blood.

Lymphocyte: A white blood cell that recognizes and destroys antigens present in the body tissues.

M

Malpighian tubule: The excretory organ of grasshoppers and other insects.

Mammalia: A class of warm-blooded vertebrates that have a four-chambered heart, are covered with hair or fur, and nourish their young with milk; mammals.

Marrow: The soft tissue that fills the hollow spaces in bone.

Medulla: The part of the brain beneath the cerebellum and continuous with the spinal cord, controls involuntary activities.

Menstrual cycle: The hormone controlled cycle in the human female, lasting about a month, in which an egg matures and is released from the ovary and the uterus prepares to receive it.

Menstruation: The last stage of the menstrual cycle, marked by the shedding of some of the uterine lining, the unfertilized egg, and a small amount of blood through the vagina, which occurs about once a month in the human female.

Menopause: The period in reproductive cycle of human females when the recurring menstrual cycle including ovulation stops.

Messenger RNA (mRNA): The type of RNA that carries the code for a polypeptide from DNA to the ribosomes where it is translated.

Metamorphosis: The series of changes that certain types of organisms undergo as they develop from a larva or nymph to an adult.

Migration: To move from one region to another.

Mimicry: A protective adaption in which one species is protected from its enemies by its resemblance to another species.

Molar: A type of tooth specialized for grinding food.

Monohybrid cross: A genetic cross in which only one pair of contrasting traits is studied.

Morula (pl. morulae): An early stage of animal development in which the embryo consists of a solid ball of cells formed by cleavage of the fertilized egg.

Motor neuron: A nerve cell that carries impulses from the spinal cord and brain toward an effector.

Multiple alleles: Three or more different forms of a gene each producing a different phenotype.

Multiple-gene inheritance: The type of inheritance in which two or more pairs of genes affect the same characteristic; polygenic inheritance.

Muscle tissue: A tissue consisting of cells that have the capacity to contract and exert a pull.

Mutation: The appearance of a new allele on a chromosome.

Mutualism: A symbiotic relationship in which both organisms benefit from their association.

Myosin: Contractile protein that interacts with actin to produce muscle contraction.

N

Natural selection: The process whereby organisms with favourable variations survive and produce more offspring than less well adapted organisms.

Navel: A scar-formed at birth when the umbilical cord is cut and tied.

Negative feedback: A regulatory mechanism that returns a condition to its normal value.

Nekton: Free swimming marine organisms, inducing fishes, turtles and whales.

Nephridium (pl. rephridia): The organ of excretion in the earthworm and other annelids.

Nephron: The functional unit of the kidney.

Nitrification: The oxidation of ammonium salts into nitrites and nitrates especially by soil bacteria.

Nerve: A bundle of axons, or fibres that are bound together by connective tissue.

Nerve net: A type of nervous system found in the hydra, the nerve cells are formed into an irregular network through which coordinated movement can occur.

Neuron: A cell specialized for the transmission of impulses; a nerve cell.

Neurotransmitter: A substance released from the synaptic knob into the synaptic cleft that initiates impulses in adjacent neurons.

Neutralization: The reaction of an acid and a base to produce a neutral solution.

Niche: The ecological position of an organism. or The particular way in which a species functions in an ecosystem.

Nictitating membrane: A transparent kind of eyelid present in many vertebrates.

Nitrifying bacteria: Bacteria that can convert ammonia to nitrite and nitrate.

Nitrogen cycle: The pathways by which nitrogen is circulated through the biosphere.

Nitrogen fixation: The process by which nitrogen fixing organisms produce nitrogen compounds from the gaseous nitrogen of the atmosphere.

Nondisjunction: The failure of homologous chromosomes to separate normally during meiosis, producing gametes or spores with one more or one less chromosome than normal.

Nonrenewable natural resource: A resource that can be used only once, such as coal, oil and minerals, and cannot be replaced.

Nucleic acid: A molecule made up of repeating units called nucleotides, which form the genetic code for transmitting hereditary information; DNA or RNA.

O

One gene, one polypeptide hypothesis: The hypothesis that every gene directs the synthesis of a particular polypeptide chain originally called the one gene, one enzyme hypothesis.

Oogenesis: The formation of eggs.

Open circulatory system: A circulatory system in which blood is not always enclosed in blood vessels, but flows into open space to both the tissues.

Operculum: A protective, bony flap that covers the gills of bony fishes, gill cover.

Optic nerve: The nerve that carries impulses from the receptors in the retina of the eye to the brain.

Outbreeding: A breeding method in which individuals not closely related are mated to introduce new beneficial alleles into the population.

Ovary: In animals, the female gonad, which produces egg cells, in flowering plants, the basal part of the pistils, which contains ovules and later, seeds and which develops into a fruit.

Oviduct: A tube that carries the egg away from the ovary that contains a female gametophyte and that develops into a seed after fertilization.

Oviparous: Organisms that lay eggs.

Ovum (pl. ova): Egg cell.

Oxygen cycle: The pathway of oxygen in the ecosystem.

Ozone hole: The thinning or depletion of ozone in stratosphere.

P

Pacemaker: A specialized group of cells in the wall of the right atrium that initiates contraction of the heart by electrical impulses.

Pancreas: An organ that is both an exocrine gland and endocrine gland and that secretes digestive juice and the hormones insulin and glycogen.

Pancreatic juice: The digestive secretion of the pancreas containing sodium bicarbonate amylase, proteases and lipases.

Parasite: A heterotroph that obtains nutrients from the living organism in or on which it lives.

Parathyroid gland: One of four small glands embedded in back of the thyroid that secrete parathormone.

Pepsin: A protein – digesting enzyme in gastric juice.

Peripheral nervous system: The division of the nervous system that includes all the neurons and nerve fibres outside the brain and spinal cord.

Peristalsis: The alternate waves of contraction and relaxation in the walls of the alimentary canal.

Permafrost: The lower layers of the soil in the tundra that remain frozen throughout the year.

Phagocytosis: The process in which large particles or small organisms are ingested into a cell.

Pharynx: The throat.

Phenotype: The physical traits that appear in an individual as a result of its genetic makeup.

Phototroph: An organism that carries out photosynthesis.

Phylum: The largest or most inclusive group within a kingdom.

Phytoplankton: Photosynthetic organisms that float near the surface of water.

Pituitary gland: The endocrine gland attached to the hypothalamus that controls the activities of many other endocrine glands in the body.

Placental mammals: A mammal in which a placenta forms during development of the embryo.

Plankton: Organisms that float in a body of water.

Plasmid: A small circular segment of DNA that is found in bacteria and that stays separate from the bacterial chromosome; used in genetic engineering.

Platelet: A small round or oval blood cells fragment that triggers the blood clotting process.

Pollution: The addition of anything to the environment that makes it less fit for living things.

Pons: A part of the brain that serves as a relay system linking the spinal cord, medulla, cerebellum, and the cerebrum.

Polygenic inheritance: Inheritance of a quantitatively variable phenotypic trait determined by interaction of numerous genes.

Population: A group of organisms of the same species living together in a given region and capable of interbreeding.

Population genetics: The study of the changes in the genetic makeup of populations.

Posterior: Pertaining to the rear or tail end of a bilaterally symmetrical animal.

Predator: A carnivore that captures and feeds on prey.

Pregnancy: In mammals, the period during which the developing embryo is carried in the uterus.

Primary succession: Succession that occurs in an area that had no previously existing life.

Progesterone: A hormone recreated by the ovaries that helps to regulate the menstrual cycle and maintains the uterus during pregnancy.

Pulmonary circulation: The pathways in which blood flows between the heart and the lungs.

Pulse: The expansion in the diameter of an artery that can be felt each time the left ventricle contracts.

Punnett square: A diagram, used in genetics, to show the results of a cross.

R

Recessive trait: The trait that is masked in the offspring of a cross between two pure individuals showing contrast-ing forms of the trait.

Recombinant DNA: DNA that has been altered by genetic engineering.

Recombination: The formation of new combinations of alleles resulting from crossing over and independent assortment during meiosis, and from gamete fusion.

Reflex: An involuntary automatic response to a given stimulus, not involving the brain.

Reflex arc: The pathway over which the nerve impulses travel in a reflex.

Regeneration: The regrowth of lost body parts by an animal.

Renal artery: One of the vessels that bring blood to the kidneys.

Renal vein: One of the vessels through which blood flows from the kidneys.

Renewable natural source: A natural resource, such as air, water, soil, sunlight and living organisms, that can be replaced by natural processes.

Reproductive isolation: The loss of ability to interbreed successfully by two groups of a population that have been separated geographically for a long time.

Rh factor: One of a group of antigens found on the surface of red blood cells.

Roughage: Indigestible material in food; fiber.

S

Salivary amylase: The enzyme in saliva that hydrolysis starch into maltose, ptylin.

Salivary gland: A gland that secretes saliva into the mouth.

Savannah: Any large area of tropical or sub tropical grassland covered in part with trees and spring shurbs.

Scavenger: A carnivore that feeds on dead animals that it finds.

Schwann cell: A type of cell that surrounds axons and forms the myelin sheath.

Scrotum (pl scrota): A sac of skin outside the body wall in which the testes of the male are located.

Selection: The process by which certain organism, or any part of their characteristics, are favored in the struggle for survival.

Secondary succession: Succession that occurs in an area in which an existing community has been partially destroyed and its balance upset.

Sex chromosome: One of two unmatched chromosomes that determine the sex of an individual, represented as X and Y.

Sex-linked trait: A trait that is controlled by a gene found on one of the sex chromosomes.

Skeletal muscle: Muscle that is attached to bone and is involved in locomotion and voluntary movement, striated muscle.

Small intestine: The part of the digestive tract where most chemical digestion and almost all absorption occurs.

Smooth muscle: Muscle tissue made up of individual cells, not marked by striations and not under voluntary control.

Social behaviour: Helpful and hostile interactions between animals of the same species.

Sodium-potassium pump: An active transport mechanism that pumps sodium ions out of, and potassium ions into, a nerve cell, sodium pump.

Somatic nervous system: The division of the peripheral nervous system that contains sensory and motor neurons that connect the central nervous system to skeletal muscles, skin and sense organs.

Sphincter: A ring of muscle that acts as a slave.

Spinal column: In vertebrates, the series of vertebrae connected by cartilage discs that surrounds and protects the spinal cord, the backbone.

Spinal cord: The cord of nervous tissue in vertebrates that extends down from the brain, running through the vertebrae of the spinal column.

Spinal nerve: A nerve connected to the spinal cord.

Spiracle: One of several paired openings through which air enters and leaves the body of terrestrial arthropods.

Strip cropping: A conservation practice in which cover crops are planted between strips of row crops, leaving no soil open to erosion.

Succession: The replacement of one community of organisms by another as conditions change.

Sympathetic nervous system: The division of the autonomic nervous system that generally accelerates body activities.

Synapse: The region where nerve impulses pass from one neuron to another.

Syndrome: An aggregate or set of concurrent symptoms indicating the presence and nature of a disease..

Systemic circulation: The circulatory pathways that carry blood from the heart to all parts of the body except the lungs.

Systole: The period of contraction during the heartbeat cycle.

T

Taiga: A biome in which the climax vegetation is evergreen forest, characterized by cold winters and warmer, moist summers.

Temperate deciduous forest: A biome in which the climax vegetation is deciduous trees, characterized by hot, humid summers and cold winters.

Template: A pattern of wood or metal used as a guide in shaping something accurately.

Tendon: A strong band of connective tissue that attaches skeletal muscle to bone.

Territory: An area defended by an individual against intrusion by members of the same species.

Test cross: A genetic cross in which a test organism showing the dominant trait is crossed with one showing the recessive trait; used to determine whether the test organism is homozygous dominant or heterozygous.

Testosterone: A male sex hormone secreted by the testes stimulates development of the male reproductive system and promotes male secondary sex characteristics.

Thalamus: A part of the brain that serves as a relay centre.

Thymus gland: A gland located in the upper chest cavity that is involved in immunity.

Thyroid: The endocrine gland that is located in front of the trachea and that secretes thyroxine and calcitonin.

Thyroxine: An iodine-containing hormone that is secreted by the thyroid and that regulates the rate of metabolism in the body.

Topography: The physical features, (viewed collectively) of a region.

Trachea (pl trachea): The tube through which air passes from the pharynx to the lungs.

Transcription: The copying of a genetic message from a strand of DNA into a molecule of RNA.

Tropical rain forest: A biome found around the equator in which ther is a constant supply of rainfall and the temperature remains at about 25°C throughout the year.

Tube foot: In echinoderms, one of many water-filled tubes ending in a suction disk; used in locomotion, feeding and respiration.

Tundra: A biome characterized by a low average temperature, permafrost, and a very short growing season.

Turgid: State of a cell full of water.

Typhlosole: A longitudinal fold in the intestinal wall of some animals that increases the surface area of the intestine.

U

Umbilical cord: In placental mammals, the structure that connects the foetus and the placenta.

Urea: A nitrogenous waste formed from ammonia and carbon dioxide.

Ureter: A tube that carries urine from a kidney to the bladder.

Urethra: The tube that carries urine from the bladder to the outside of the body.

Uric acid: A dry, nitrogenous waste product excreted by bird, reptiles and insects.

Urinary bladder: A sac-like organ where urine is stored before being excreted.

Urine: An excretory liquid composed of water, urea and salts.

Uterus: The thick, muscular, pair shaped organ in the female mammal in which the embryo develops.

V

Vagina: The structure leading from the uterus to the outside of the body in mammalian females; the birth canal.

Valve: A flaplike structure that permits body fluids to flow in only one direction, or that opens and closes a tube or opening.

Vas deferens: The tube that carry sperm from each testis to the urethra.

Vector: An organism that carries pathway from one host to another.

Vein: In leaves, a structure that contains the vascular tissues. In animals, a blood vessel that carries blood from the body tissues to the heart.

Ventral: Pertaining to the lower or belly side of a bilaterally symmetrical animal.

Ventricle: One of the lower thick walled chambers of the heart, a space within the human brain that is filled with cerebrospinal fluid.

Vertebra (pl vertebrae): One of the bones of the spinal column that surrounds and protects the spinal cord.

Vestigial structure: A nonfunctional structure in an organism that is a remnant of a structure that was functional in some ancestral form of the organism.

Villus (pl villi): A small, fingerlike projection of the lining of the small intestine.

Viviparous: Organisms whose embryo develop within the body of the mother and derive their nourishment from the mother.

W

Water cycle: The cycling of water between the surface of the earth and the atmosphere.

White blood cell: See leukocyte.

X

Xerosere: The series of changes in the succession of the plant community found upon dry soil.

Y

Yolk: Stored food in an animal egg.

Yolk sac: In shelled eggs, the extraembryonic membrane that surrounds the yolk, containing blood vessels that transport food to the embryo, in mammals, an extraembryonic membrane that forms part of the umbilical cord.

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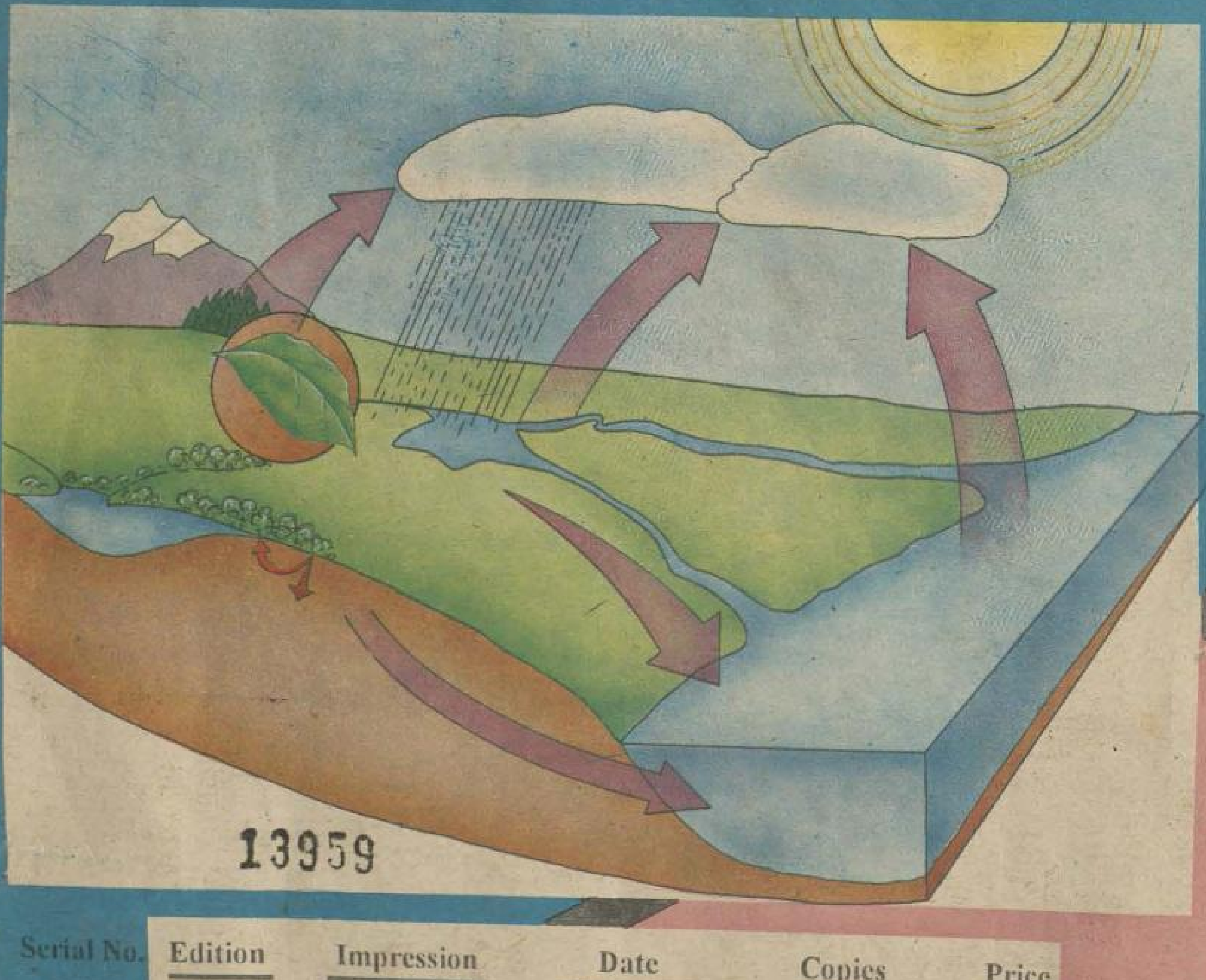
Stop smoking

It is Injurious to Health



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